Part III:

MEASURE ANALYSIS and LIFE-CYCLE COST

2005 California Building Energy Efficiency Standards

CALIFORNIA ENERGY COMMISSION

Contract Number 400-00-061

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Introduction

This report contains the results of initiatives to upgrade and improve the 2001 California energy efficiency standards for residential and nonresidential buildings. The revisions will be adopted in 2003 for implementation in 2005.

Potential measure analysis initiatives and proposed standards changes were submitted and discussed at staff workshops on October 22, November 15, and November 16, 2001. The California Energy Commission (CEC) identified priority measures and funded analysis initiatives on a subset of these measures. Other parties have also funded further analysis initiatives; however these analyses are not included in this document.

This document contains Part III of the report, which includes the measures analyzed under contract to the CEC that will be discussed in a staff workshop on July 18, 2002. Part I contained the measures discussed at the April 23, 2002 workshop, and Part II included the measures covered during a workshop on May 30, 2002.

Summary of Measures

The following measures and modifications are addressed in this document:

- Residential Heating, Ventilation and Air Conditioning

    Maximum Allowable Cooling Capacity. Oversizing causes greater peak demand and cycling. This mandatory requirement allows equipment to be sized to the building loads, with larger systems being allowed if the equipment performance is better than average.

    Residential Duct Systems. Three recommendations for improving residential duct systems are covered in this initiative. A prescriptive change increases duct insulation in some climate zones from R-4.2 to R-8, while the banning of porous inner core flex ducts is a mandatory change. Additionally, builders will have to measure both fan energy and air flow to take credit for reduced fan energy. Ducts are commonly undersized, which results in either inadequate airflow in the building, or larger fans being used to provide the necessary air flow. This proposed compliance option will improve the treatment of energy requirements for air flow and fan energy.

- Residential Insulation

    Residential Construction Quality for Attics. “Real” attic thermal performance is degraded from ideal performance by two factors: common insulation installation defects, imperfect air barriers, absence of draft stops, and missing or improperly installed kneewall insulation. This initiative analyzes how the overall effective insulation U-values differs from the standard calculated U-values, after the installation defects are considered. It recommends degrading the R-value of the cavity insulation in a neutral manner when industry standard methods are used, providing a credit when a high quality wall construction is independently verified. This represents only part of the study; construction quality in walls was considered at an earlier hearing.

- Nonresidential Lighting

    Revised Tailored Method This measure revises the procedure for determining the allowed lighting power levels for interior spaces using the Tailored Method, which permits development of a power budget on a space-by-space, task-by-task basis.

Acknowledgements

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- *Maximum Allowable Cooling Capacity* – This report was completed by Bruce Wilcox of the Berkeley Solar Group, Ken Nittler of Enercomp, Inc., and John Proctor of Proctor Engineering Group.
- *Residential Duct Systems* – This report was completed by Bruce Wilcox of Berkeley Solar Group and John Proctor of Proctor Engineering Group.
- *Residential Construction Quality for Attics* – This report was completed by Berkeley Solar Group, Chitwood Energy Management, and Davis Energy Group, Inc. Field work was completed by Chitwood Energy Management and Amaro Construction as subcontractors to Davis Energy Group under the Commission's Residential Construction Quality Assessment Project.
- *Revised Tailored Method* – This proposal was developed by James Benya, Benya Lighting Design and Maziar Shirakh of the California Energy Commission with significant input from Bill Pennington and Gary Flamm of the California Energy Commission and Charles Eley of Eley Associates.

Maximum Allowable Cooling Capacity

Overview

This initiative proposes to establish a maximum allowable cooling capacity and to require that the installed cooling capacity not exceed this value. Exceptions are provided if the cooling system is not an electrically driven compression system and if the proposed equipment uses less electrical energy than the standard equipment.

Description

The residential standards do not currently impose limits on the size of air conditioners that can be installed, even though the size has a major impact on peak demand for electricity. This proposal introduces a maximum allowable cooling capacity for electrically driven compressor cooling systems into the standards as a mandatory measure designed to prevent gross oversizing of air-conditioning systems. Approved ACM software is required to provide this calculation.

The calculations necessary to establish the maximum allowable cooling capacity are separated into two procedures. The first proposed procedure adapts industry-standard sizing calculations as published in Chapter 28 of the *2001 ASHRAE Handbook — Fundamentals* to calculate the design cooling capacity for the proposed building. The calculations are required to use many of the same methods and values specified in the ACM manual for energy calculations. Examples include the use of the U-factors, SHGC values, infiltration levels, duct efficiencies, and radiant barrier models from the ACM manual.

The design cooling capacity is then used in a second procedure to establish the maximum allowable cooling capacity. The maximum allowable cooling capacity is adjusted to rated conditions for comparison with published air conditioner cooling capacities. It also includes adjustments that recognize that air conditioning units are typically available in 0.5-ton increments below 4 tons of capacity, 1-ton increments between 4 and 5 tons, and 2.5-ton increments above 5 tons.

Compliance is achieved by installing an air conditioner with a capacity smaller than the maximum allowable cooling capacity. Two exceptions are provided. The first exception allows buildings without a cooling system, or if the cooling system is not an electrically driven compression cooling system, to skip the proposed requirements. The second exception allows the maximum allowable cooling capacity to be exceeded if the proposed total electrical input is less than or equal to the standard total electrical input.

Additional considerations:

1. Design Data. Energy compliance is calculated based on the 16 climate zones, each of which has a standard weather file. The maximum allowable cooling capacity will need to respond to the differences in design conditions within the climate zones using ASHRAE design data. This means that there is a different sizing compliance requirement in each climate area within a climate zone.
2. Multiple Orientations. Compliance calculations for production houses are currently done with the house rotated to each of the four cardinal orientations. If the house design complies in each of the four orientations, it is deemed to comply in any orientation. If there is more than one zone, it is likely that the design cooling loads will vary by orientation and that the largest design cooling load occurs on different orientations. The proposed language allows the largest design cooling load for each zone to be used, even if they are for different orientations, when calculating the maximum allowable cooling capacity.
3. Block Loads. Current compliance practice often treats the entire building as a single zone. This proposal continues to allow this practice but adds a restriction that, when individual zones are modeled, each zone must be served by a separate cooling system when calculating the maximum allowable cooling capacity to be consistent with ASHRAE Chapter 28 calculations.
4. Table Selection. ASHRAE Chapter 28 provides tables of cooling load temperature differences and glass load factors that vary with the type of structure, zoning, and wall orientations that can significantly alter

the magnitude of the design cooling load. A simple set of rules is provided in the design cooling load procedure to ensure consistent and appropriate table selection.

Benefits

A reduction in the peak electrical demand imposed by new homes on the state's electricity supply is the primary benefit of this proposal. Data from field surveys indicates that installed air conditioners are typically larger than actually needed to meet the design load. Air conditioners operating on peak demand in California's hot Central Valley climates typically draw 1.7 kW/ton of rated capacity or more.

In addition, correctly sized air conditioners will provide better latent load capability and increased comfort for homebuyers. Oversizing causes excess cycling, which reduces the ability to remove latent loads and makes the occupant less comfortable because of high indoor relative humidity. This leads to callbacks for contractors who often try making the unit bigger, thereby exacerbating the problem.

If builders and buyers perceive a small air conditioner to be less desirable, sizing rules might become a disincentive for good envelope measures. Building a low energy envelope from a cooling load point of view (low solar gain glass, shading, cool roof, better insulation) would reduce the allowable air conditioner size, whereas providing energy compliance by utilizing other measures such as higher cooling efficiency or high efficiency heating or water heating equipment would allow the air conditioners to remain oversized. Therefore, in order to keep air conditioner sizes comparable to those currently used, builders may begin using trade-offs, replacing prescriptive envelope requirements with higher efficiency heating or water heating equipment to bypass the new sizing requirement.

Environmental Impact

The positive environmental impact of this proposal results from less on-peak electricity production by low-efficiency peaking plants and a reduced need for new generating capacity.

Type of Change

This proposal expands the scope of the standards to recognize that oversized cooling systems have a substantial impact on peak electrical demand and that the cooling capacity should be limited to a reasonable size. No additional efficiency measures are required under this proposal, just the requirement that when a cooling system is installed, it should be appropriately sized.

The proposal includes modifications to the mandatory measures in Section 150(h) of the standards and new appendices L, M, and N in the Residential ACM manual. Compliance forms will need to be modified to include documentation of the maximum allowable cooling capacity and to provide for tracking of field verification by the building official, installer certification on the CF-6R, and field verification on the CF-4R for the sizing tradeoff method in Appendix N of the Residential ACM manual. Additional language will be needed to describe this new requirement.

Proposed Measure Availability and Cost

While no additional efficiency measures are required under this proposal, it does expand the existing cooling load calculation requirements to calculate of the maximum allowable cooling capacity following a specific set of rules. Under this proposal, approved ACM software must include this calculation, so there will be effectively no added cost when the performance method is used for compliance. This calculation is also required when the prescriptive approach is used, so there is some negligible added calculation cost for this case given that load calculations are already required under the current Section 150(h) 1.

Implementation of this requirement may result in cost savings whenever a smaller cooling system is installed as a result of the maximum allowable cooling capacity. Under the AB970 proceeding, decreasing the air conditioner compressor size was estimated to save $400 per ton.

Useful Life, Persistence and Maintenance

The peak demand savings provided by a smaller capacity system are very reliable and will persist for the life of the system. Limiting oversized cooling systems is also a reliable way to ensure that the savings associated with the envelope requirements of the standards are realized. There is a potential persistence issue if split-system outdoor units are replaced with larger capacity units after final inspection.

Performance Verification

In most cases, no performance verification is required under this proposal. Verification by the field inspector consists of simply comparing the rated capacity of the installed air-conditioning units with the maximum allowed cooling capacity printed on the compliance forms.

In cases where the exception for electrical input as described in Appendix N is used, third-party HERS verification is required.

Cost Effectiveness

As noted in the Benefits section above, data from field surveys indicate that installed air conditioners are typically larger than actually needed to meet the design load. Limiting equipment size will result in the installation of smaller equipment than is currently installed in standard practice. These smaller equipment sizes will result in an immediate equipment purchase cost savings from this measure. Current standards already require calculations of the sizing; thus there is no added cost for performing the sizing calculations required by this measure. Costs for verifying that the installed equipment size meets the sizing design limit are estimated to be substantially less than the initial cost reduction from installing smaller equipment. Therefore, this proposal is immediately cost effective without additional consideration of peak savings benefits.

Relationship to Other Measures

Sizing calculations would support the TDV analysis which implements models for heat pumps where size is an issue.

Methodology

Because California cooling climates feature high solar radiation, high outdoor temperatures, and low humidity, the proposed sizing methodology is based on the sensible load only, and equipment is expected to operate with low latent load fractions. However, it is necessary to convert the calculated required sensible capacity at the outdoor design temperature to the total capacity at the standard rating condition of 95°F and an indoor return wet bulb temperature of 67°F in order to compare with manufacturers rated cooling capacity of their equipment. The conversion is done using the following empirical equation:

Design Cooling Capacity (Btu/hr) =

Design Cooling Load (Btu/hr)/(0.88 – (0.002286 x (Outdoor Cooling Design Temperature (°F) – 95)))

The equation and coefficients were developed from an analysis of manufacturers’ performance data for typical systems and the assumption that the indoor wet bulb return temperature would typically be 62°F, based on analysis of data collected in field data surveys in California homes.

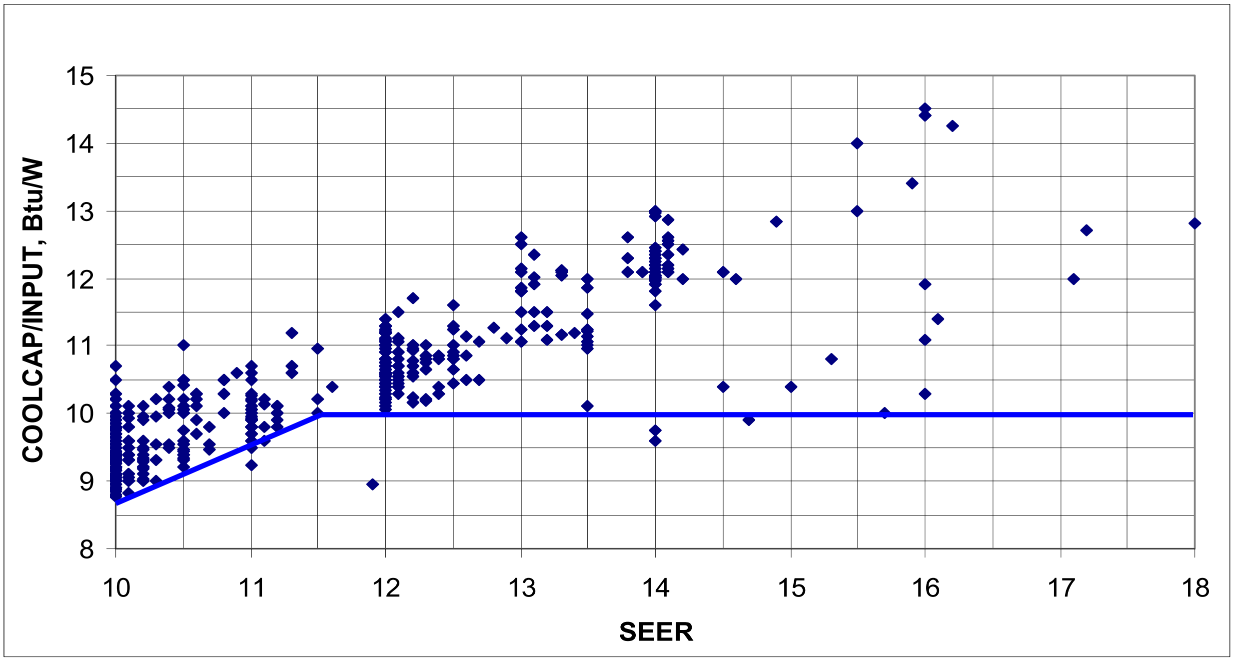

Figure 1 – W/Btu Cooling Capacity for Split Air Conditioners in the CEC Directory

The electrical input for a standard air conditioner is based on the heavy line in Figure 1, which represents the California Energy Commission (CEC) assumption plotted over data for all currently certified split air conditioners. For the 2005 Standards, we assume a minimum SEER 12 unit, which has a cooling capacity to power ratio of 10 Btu/W, or 0.1 W/Btu. This value includes both outdoor compressor power and indoor air handler fan power at the test default of 0.365 W/cfm.

Based on field surveys, the average fan consumes 0.51 W/cfm of airflow. The required airflow for the proposed airflow and fan energy credit is 400 cfm/ton of cooling capacity. Combining these terms yields an average fan power of:

$$0.51 * 400 / 12000 = 0.017 \text{ W/Btu}$$

Precise treatment of the fan energy would require that the default fan of .365 W/cfm included in the rated input be subtracted from both the Standard and Proposed system. However, for compliance, it is convenient and mathematically equivalent to leave the default fan in the rated electrical input value and add it to the measured fan power. The Standard Design value is then:

$$.1 + .017 = .117 \text{ W/Btu}$$

And the Proposed Design value is:

CEC Directory AC Unit Electrical Input Watts + Measured Fan Watts (or 0.017 * capacity if fan watts are not measured).

Recommendations

Proposed Standards Language

The following changes are proposed for the standards:

SUBCHAPTER 7 OW-RISE RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150 – MANDATORY FEATURES AND DEVICES

Any new construction in a low-rise residential building shall meet the requirements of this section.

…

(h) **Space-conditioning equipment.**

1. **Building cooling and heating loads.**

   Building cooling and heating loads ~~design heat loss rate and design heat gain rate~~ shall be determined using a method based on any one of the following:

   A. The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) Handbook and Product Directory, Equipment Volume (2000~~1996~~), HVAC Applications Volume (1999~~6~~), and Fundamentals Volume (2001~~1993~~), or

   B. The Sheet Metal Air Conditioning Contractors National Association (SMACNA) Residential Comfort System Installation Standards Manual, 7th edition (1998) ~~Installation Standards for Residential Heating and Air Conditioning Systems~~, or

   C. The Air Conditioning Contractors of America (ACCA) Manual J, Version 8 (2002).

   The cooling and heating loads ~~design heat loss rate and design heat gain rate~~ are two of the criteria that shall be used for equipment sizing and selection.

   NOTE to Section 150 (h) 1: Heating systems must meet the minimum heating capacity required by UBC Section 310.11. The furnace output capacity and other specifications are published in the commission's directory of certified equipment or other directories approved by the commission.

2. **Design conditions.**

   For the purpose of sizing the space-conditioning (HVAC) system, the indoor design temperatures shall be 70°F for heating and 75~~8~~°F for cooling. The outdoor design temperatures for heating shall be no lower than the Winter Median of Extremes column. The outdoor design temperatures for cooling shall be from the 0.5 percent Summer Design Dry Bulb and the 0.5 percent Wet Bulb columns for cooling, based on percent-of-year in ASHRAE publication *SPCDX: Climate Data for Region X, Arizona, California, Hawaii, and Nevad*a, 1982 and its supplement, 1994, incorporated herein by reference.

3. **Maximum allowable cooling capacity.**

   The maximum allowable cooling capacity shall be determined in accordance with procedures set forth in Appendix L and Appendix M of the *Residential ACM Manual*. If the maximum allowable cooling capacity is calculated for the entire building, the total installed cooling capacity shall not exceed the maximum allowable cooling capacity. If the maximum allowable cooling capacity is calculated for each zone or dwelling within a building that is served by its own cooling system, the installed cooling capacity for each cooling system shall not exceed the maximum allowable cooling capacity calculated for the cooling system. For buildings demonstrating compliance using the multiple orientation alternative of Section 151(c), the maximum allowable cooling capacity is the highest of the four cardinal orientations.

EXCEPTION 1 to Section 150 (h) 2: If no cooling system is installed or if the installed system is not an electrically driven compression cooling system, the requirements of the section do not apply and the calculation of the maximum allowable cooling capacity is not required.

EXCEPTION 2 to Section 150 (h) 2: The installed cooling capacity shall be permitted to exceed the maximum allowable cooling capacity if the electrical input of the oversized cooling system is less than or equal to the electrical input of a standard cooling system determined in accordance with Appendix N of the *Residential ACM Manual*.

APPENDIX 1-A STANDARDS REFERENCED IN ENERGY EFFICIENCY REGULATIONS

…

AIR CONDITIONING CONTRACTORS OF AMERICA

Manual J – Residential Load Calculation

Available from: Air Conditioning Contractors of America, Inc.
1712 New Hampshire Avenue, NW
Washington, DC 20009
http://www.acca.org/catalog/product.asp
PHONE (202) 483-9370
FAX (202) 232-8545

…

AMERICAN SOCIETY OF HEATING, REFRIGERATION, AND AIR-CONDITIONING ENGINEERS

(NATIONAL PUBLICATIONS)

Handbook and Product Directory

Equipment Volume, 2000 Edition

HVAC Applications Volume, Chapter 48, 1999 Edition

Fundamentals Volume, ~~1993, and 1997~~ and 2001 Edition

STANDARDS

ANSI/ASHRAE 55-1992 Thermal Environment Conditions for Human Occupancy

ASHRAE 62-89 Standards for Natural and Mechanical Ventilation and Ventilation for Acceptable Indoor Air Quality

Available from: ASHRAE
1791 Tullie Circle N.E.
Atlanta, Georgia 30329
(404) 636-8400 or (800) 527-4723
http://www.ashrae.org/

AMERICAN SOCIETY OF HEATING, REFRIGERATION, AND AIR-CONDITIONING ENGINEERS
(REGIONAL PUBLICATIONS)

~~Recommended Outdoor Design Temperatures for Northern California, 1977~~

~~Available from: ASHRAE~~
~~Golden Gate Chapter~~
~~370 Brannan Street~~
~~San Francisco, California 94102~~
~~(415) 495-4552~~

~~Climatic Data For Region X, Arizona, California, Hawaii, and Nevada, Publication SPCDX, 1982~~

~~Available from: ASHRAE - Climatic Data~~
~~Southern California Chapter~~
~~Post Office Box 6306~~
~~Alhambra, California 91802~~

Climatic Data for Region X Arizona, California, Hawaii, Nevada, Publication SPCDX, 1982, ISBN #20002196

Supplement to Climatic Data for Region X Arizona, California, Hawaii, Nevada, 1994, ISBN #20002596

Available from: Order Desk
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http://www.bnibooks.com/

Proposed ACM Language

Add language to make Appendix L and M calculations mandatory for ACM's:

1.2.1 Minimum Modeling Capabilities

Minimum modeling capabilities must be included in all ACMs. If a candidate ACM does not have all of these capabilities, then it cannot be approved for compliance. The minimum modeling capabilities are summarized below:

…

- Calculation of the design cooling capacity, maximum allowable cooling capacity and proposed total electrical input as described in Appendices L, M and N.

Add the following Appendices to Residential ACM Manual:

APPENDIX L

Procedure for Calculating Design Cooling Capacity

The following rules apply when calculating the design cooling capacity as required by Section 150(h)3 of the standards:

1. **Methodology**. The methodologies, computer programs, inputs, and assumptions approved by the commission shall be used.
2. **Cooling loads.** Except as specified in this section, calculations will be done in accordance with the method described in Chapter 28, Residential Cooling and Heating Load Calculations, *2001 ASHRAE Handbook -- Fundamentals*. Interpolation shall be used with tables in Chapter 28. The methods in Chapter 29 may not be used under this procedure.
3. **Indoor design conditions**. The indoor cooling design temperature shall be 75°F. An indoor design temperature swing of 3°F shall be used.
4. **Outdoor design conditions**. Outdoor design conditions shall be selected from ASHRAE publication SPCDX: *Climatic Data for Region X, Arizona, California, Hawaii, and Nevada*, 1982 and its supplements. Outdoor cooling design dry bulb temperatures shall be no greater than the temperature listed in the Summer Design Dry Bulb 0.5 percent column.
5. **Block loads**. The design cooling capacity used for calculating the maximum allowable cooling capacity is based on the block (peak) load either for:
    a. The whole building; or
    b. For each zone within a building that is served by its own cooling system; or
    c. For each dwelling unit within a building that is served by its own cooling system.

    Room-by-room loads are not allowed for calculating the design cooling capacity.
6. **Table selection**. Tables 2 (cooling load temperature differences) and 4 (glass load factors) shall be used for:
    a. Buildings with more than one dwelling unit using whole building block loads; or
    b. Buildings or zones with either east or west exposed walls but not both east and west exposed walls.

    Otherwise, Tables 1 (cooling load temperature differences) and 3 (glass load factors) shall be used.
7. **U-factors.** U-factors for all opaque surfaces and fenestration products shall be consistent with the methods described in Section 4.2 of the *Residential ACM Manual*. The effects of radiant barriers or cool roofs shall be included if these features are in the proposed building.
8. **Solar heat gain coefficients.** Solar heat gain coefficients (SHGC) shall be equal to the $SHGC_{closed}$ values described in Section 4.4.2 of the *Residential ACM Manual.*
9. **Glass load factors**. Glass load factors (GLFs) shall be calculated using the equation in the footnotes of Tables 3 and 4 in Chapter 28 using the columns for "Regular Double Glass" and the rows for "Draperies, venetian blinds, etc". The table values used in the equation shall be $U_t = 0.55$ and $SC_t = 0.45$. The shading coefficient for the alternate value shall be $SC_a = SHGC \times 0.87$ where the SHGC value is described above. The GLF values shall also be adjusted for latitude as described in the footnotes.

10. **Infiltration**. The air flow (cfm) due to infiltration and mechanical ventilation shall be calculated with the effective leakage area method as documented in equation 4.19 in Section 4.17.1 of the *Residential ACM Manual* using the outdoor design temperature minus the indoor design temperature as the temperature difference and a 7.5 mph wind speed.
11. **Internal gain**. Occupancy shall be assumed to be two persons for the first bedroom and one person for each additional bedroom per dwelling unit. Each person shall be assigned a sensible heat gain of 230 Btu/hr. Appliance loads shall be 1200 Btu/hr for multifamily buildings with common floors and ceilings. Otherwise the appliance load is 1600 Btu/hr.
12. **Cooling duct efficiency**. The cooling duct efficiency shall be calculated using the seasonal approach as documented in Section 4.19 and Appendix F of the *Residential ACM Manual.*
13. **Latent factor.** The latent factor shall be 1.0.
14. **Total cooling load.** The total cooling load is calculated in accordance with Table 9 of Chapter 28 with the values specified in this section.
15. **Design cooling load.** The design cooling load is equal to the total cooling load divided by the cooling duct efficiency.
16. **Design cooling capacity.** The design cooling capacity calculation adjusts the sensible design cooling load to estimate the rated cooling capacity needed as follows:

    Design Cooling Capacity (Btu/hr) =

    Design Cooling Load (Btu/hr) / (0.88 – (0.002286 x (Outdoor Cooling Design Temperature (°F) – 95))).

APPENDIX M

Procedure for Calculating Maximum Allowable Cooling Capacity

The following rules apply when calculating the maximum allowable cooling capacity as required by Section 150(h)3 of the standards:

1. **Design cooling capacity.** The design cooling capacity shall be calculated in accordance with the procedure described in Appendix L of the *Residential ACM Manual*.
2. **Maximum allowable cooling capacity.** For buildings with a single cooling system or for buildings where the design cooling capacity has been calculated separately for each cooling system, the maximum allowable cooling capacity for each cooling system shall be:

Design Cooling Capacity (Btu/hr)	Maximum Allowable Cooling Capacity (Btu/hr)
< 48000	Design Cooling Capacity + 6000
48000 - 60000	Design Cooling Capacity + 12000
>60000	Design Cooling Capacity + 30000

For buildings with more than one cooling system where the design cooling capacity has been calculated for the entire building, the maximum allowable cooling capacity for the entire building shall be:

Maximum Allowable Cooling Capacity (Btu/hr) = Design Cooling Capacity (Btu/hr) + (6000 (Btu/hr) x Number of Cooling Systems)

3. **Multiple Orientations**. For buildings demonstrating compliance using the multiple orientation alternative of Section 151(c), the maximum allowable cooling capacity is the highest of the four cardinal orientations. For buildings with more than one cooling system, the orientation used for determining the maximum allowable cooling capacity shall be permitted to be different for each zone.

APPENDIX N

Procedure for Determining Electrical Input Exception for Maximum Allowable Cooling Capacity

In accordance with the exception to Section 150(h)2, the installed cooling capacity shall be permitted to exceed the maximum allowable cooling capacity if the electrical input of the oversized cooling system is less than or equal to the electrical input of a standard cooling system using the following rules:

1. **Design cooling capacity.** The design cooling capacity shall be calculated in accordance with the procedure described in Appendix L of the *Residential ACM Manual*.
2. **Standard total electrical input.** The standard electrical input is calculated as follows:

   Standard Total Electrical Input (W) = 0.117 (W/Btu/hr) x Design Cooling Capacity (Btu/hr).
3. **Proposed electrical input.** The proposed electrical input (W) for the installed cooling system is published as the "Electrical Input" in the Directories of Certified Appliances maintained by the California Energy Commission in accordance with the requirements of the Appliance Standards.
4. **Proposed fan power.** The proposed fan power (W) of the installed cooling system is equal to either:
   a. 0.017 (W/Btu/hr) x Design Cooling Capacity (Btu/hr); or
   b. The measured fan power (W) where the measured fan power is determined using the procedure described in Appendix [X - TO BE SPECIFIED IN DUCTS REPORT]of the *Residential ACM Manual*.
5. **Proposed total electrical input.** The proposed electrical input is equal to:

   Proposed Total Electrical Input (W) = Proposed Electrical Input (W) + Proposed Fan Power (W).

   For buildings with more than one cooling system, the proposed total electrical power shall be the sum of the values for each system. If the proposed total electrical input is less than or equal to the standard total electrical input, then the installed cooling capacity may exceed the maximum allowable cooling capacity.

Bibliography and Other Research

American Society of Heating, Refrigerating, and Air-Conditioning Engineers. *ASHRAE Handbook -- Fundamentals, 2001*. Chapter 28, pages 28.1-28.6. ASHRAE: Atlanta, GA.

California Energy Commission. Appliance Directories. 2002.

Residential Ducts

Overview

Duct and air handler fan systems are an integral part of the vast majority of residential HVAC systems in new California homes. Inefficiencies in these systems have traditionally consumed 1/3 or more of the gas and electricity used for heating and cooling. This report proposes a set of improvements to duct insulation and the treatment of fan energy that will deliver significant energy and peak demand savings in new homes.

Description

Duct Insulation

Based on life-cycle cost analysis, we propose raising the prescriptive R-factor for ducts from the current R-4.2 to R-8 in Climate Zones 1 through 5 and 9 through 16.

Air Conditioning Air Flow and Fan Energy

We propose an improved treatment of air-conditioning system airflow and indoor air handler fan energy including a new optional approach to measurement and field verification and a new optional credit for verified low fan watts. This change replaces the current airflow credit for Manual D duct design and places the credit for TXVs in only one location (as an option to verified refrigerant charge). Builders who choose to take credit for reduced fan watts will be required to measure and certify the actual installed fan watts using a watt meter and actual air flow using one of three methods: Plenum Pressure Matching, Flow Plate, or Flow Capture Hood. Any of these three flow measurements will also be allowed as an alternate to the temperature split method specified in the refrigerant charge verification procedure.

Porous Inner Core Flex Duct

Porous Inner Core flex ducts that use the outer vapor barrier as the only air barrier are obviously unsuitable because of their potential for leaks. We propose changes in the standards to eliminate their use.

Benefits

Improving the efficiency of duct systems significantly reduces the energy use and peak loads of the connected heating and cooling systems. Reducing fan watts reduces the peak loads and energy consumption of heating and cooling systems in a manner typically not accounted for in the appliance standards. Increasing duct R-values and reducing fan watts also allows smaller system sizing to meet the building loads. Increased duct insulation also reduces the overall loss from the building when the air handler is off, when convection from the occupied spaces makes the duct system thermally part of the building envelope.

Environmental Impact

The overall environmental impact of improving the efficiency of duct systems is highly favorable with benefit from reduced energy use and peak demand. Elimination of porous inner core flex duct will increase efficiency and useful life of duct systems and reduce the potential for insulation fiber pollution in habitable areas. Increased duct R-value will increase the demand for insulation materials.

Type of Change

This proposal involves changes to the prescriptive standards and the performance approach that requires changes in the standards, ACM Manual, and Residential Design Manual.

Measure Availability and Cost

R-8 flex ducts are widely available and have been required in other states for more than 10 years. We estimate the added cost for R-8 would be $108 for the CEC 1761 prototype. Higher efficiency air handler fans and motors that could be used to qualify for the optional reduced fan wattage compliance credit are available from many manufacturers at costs to the consumer of less than $400. Airflow and motor watt measurement devices are available to the industry at reasonable prices and their use will enable quick and accurate verification of installed fan and duct system quality. Flex ducts with an airtight inner core cost the same as porous inner core flex ducts. Successful implementation of this initiative involves training of contractors to do the proper installation and measurement, and HERS raters to perform the inspection task. Additional contractor and HERS rater training including a field inspection training component will be needed to achieve the required level of competence.

Useful Life, Persistence and Maintenance

Duct system improvements will provide consistent and persistent savings over the lifetime of the building and have no maintenance requirements.

Performance Verification

Performance verification is a key element of the airflow and fan wattage part of this proposal. Performance verification provides the assurance to the builder and HVAC contractor that the airflow and low fan energy are actually in place to ensure proper air conditioner performance and energy savings. The air-conditioning contractor and the HERS rater must be provided with the proper training to carry out the installation and test procedures.

Analysis Tools

MICROPAS/CALRES can be used to evaluate the compliance credit offered for airflow and fan watts. Micropas has been used to evaluate the energy savings and life cycle cost impacts of this proposal.

Relationship to Other Measures

Adoption of improved ducts will result in higher heating and cooling system efficiencies and will tend to decrease the cost effectiveness of other related measures. Otherwise duct measures are independent of other measures.

Methodology

Duct Insulation

We estimated energy savings for the 1761 prototype house using the 2001 ACM manual seasonal distribution efficiencies and the proposed 2005 ACM manual hourly HVAC model implemented in the research version of Micropas. We assumed the proposed 2005 ACM rules, SEER 12 air conditioner, 20% glazing and degraded insulation. We collected duct insulation cost information from the flex duct and insulation industry (Ware, 2002). We estimated duct insulated surface area for the 1761 prototype to be 564 ft^2 based on the ACM manual rules.

Air Conditioning Air Flow and Fan Energy

We estimated the impact of reduced fan watts on energy using the proposed 2005 ACM manual hourly HVAC model implemented in the research version of Micropas.

Porous Inner Core Flex Duct

Measured duct leakage data for porous inner core flex ducts shows that they have high leakage rates (Blasnik et al 1995b, Page 2-9). The Florida Building Code Section 410.1.ABCD.3.3 Page 13.57 simply states: "Flexible ducts having porous inner cores shall not be used." We propose to copy that language.

Results

Duct Insulation

Table 1 – Cost of Increased Duct Insulation

Insulation	Cost to Home buyer		Increased Cost for Added R compared to R-4.2	
R-value	$/linear foot	$/ft2 of duct surface	$/ft2 of duct surface	Total $ for 1761 prototype
R-4.2	0.83	0.35		
R-6	1.10	0.47	0.11	65
R-8	1.28	0.54	0.19	108

Table 1 shows the cost to the homebuyer of three levels of duct insulation for the CEC 1761 prototype house (Ware, 2002). These costs were based on the cost of 9-in. flex duct, thought to represent the average insulation incremental cost. The added cost for R-6 insulation in the prototype is $65. The total cost of increasing from R-4.2 to R-8 is $108.

Table 2 – Life Cycle Energy Cost Savings for Upgrade from R-4.2 to R-6 Duct Insulation for Attic Ducts

	Annual LCC Approach			TDV LCC Approach		
CTZ	Gas	Elect	Total	Gas	Elect	Total
1	135	0	$135	135	0	$135
2	165	28	$194	163	56	$219
3	90	7	$97	89	15	$105
4	113	11	$123	112	15	$128
5	98	4	$101	94	13	$107
6	33	7	$40	33	18	$51
7	33	4	$36	33	8	$41
8	43	11	$53	38	23	$61
9	48	32	$79	48	64	$112
10	60	64	$124	61	125	$186
11	145	81	$227	148	138	$286
12	128	43	$170	128	84	$212
13	100	113	$213	102	173	$276
14	173	124	$297	173	219	$393
15	20	379	$399	23	549	$571
16	375	28	$404	378	54	$431

Table 3 – Life Cycle Energy Cost Savings for Upgrade from R-4.2 to R-8 Duct Insulation for Attic Ducts

	Annual LCC Approach			**TDV LCC Approach**		
CTZ	**Gas**	**Elect**	**Total**	**Gas**	**Elect**	**Total**
1	220	0	$220	217	0	$217
2	260	50	$310	263	92	$355
3	145	14	$159	143	28	$171
4	180	14	$194	181	26	$207
5	155	7	$162	151	20	$171
6	50	14	$64	51	28	$79
7	50	4	$54	54	13	$66
8	65	18	$83	64	41	$105
9	75	53	$128	74	102	$176
10	93	103	$195	100	199	$299
11	235	135	$370	235	222	$457
12	205	67	$273	207	135	$342
13	163	181	$343	166	278	$444
14	273	198	$471	281	352	$633
15	35	609	$644	36	880	$916
16	601	50	$650	600	87	$686

Table 4 – Life Cycle Energy Cost Savings for Upgrade from R-4.2 to R-6 Duct Insulation for Crawl Space Ducts

	Annual LCC Approach			**TDV LCC Approach**		
CTZ	**Gas**	**Elect**	**Total**	**Gas**	**Elect**	**Total**
1	120	0	$120	120	0	$120
2	148	25	$172	148	43	$191
3	80	7	$87	79	10	$89
4	103	7	$110	102	10	$112
5	85	4	$89	87	5	$92
6	30	4	$34	31	10	$41
7	30	4	$34	31	5	$36
8	35	11	$46	38	18	$56
9	43	25	$67	41	51	$92
10	55	57	$112	56	102	$158
11	135	71	$206	135	115	$250
12	118	35	$153	117	66	$184
13	93	92	$185	92	140	$232
14	153	110	$262	158	194	$352
15	18	337	$354	18	477	$495
16	335	18	$353	334	33	$367

Table 5 – Life Cycle Energy Cost Savings for Upgrade from R-4.2 to R-8 Duct Insulation for Crawl Space Ducts

	Annual LCC Approach			**TDV LCC Approach**		
CTZ	**Gas**	**Elect**	**Total**	**Gas**	**Elect**	**Total**
1	195	0	$195	196	0	$196
2	238	43	$280	240	71	$311
3	128	11	$138	128	18	$145
4	165	11	$176	166	15	$181
5	140	7	$147	138	10	$148
6	48	11	$58	48	18	$66
7	45	4	$49	46	8	$54
8	60	14	$74	61	28	$89
9	68	43	$110	69	82	$151
10	88	89	$176	89	166	$255
11	218	113	$331	217	189	$406
12	190	60	$250	189	110	$299
13	148	152	$300	148	225	$372
14	248	177	$425	255	311	$566
15	33	546	$578	31	768	$799
16	538	32	$570	538	54	$592

Table 2 through Table 5 show the life cycle cost of energy savings for ducts in the 1761 prototype house in each climate zone. Heating and cooling savings are shown separately and totaled. Accounting is done with both the Annual LCC approach and the Time Dependant Valuation (TDV) approach.

Comparison of the costs from Table 1 with the savings from Table 2 and Table 4 shows that the total life cycle savings is greater than the insulation added cost for R-6 ducts in climate zones 1-5 and 9-16 under either Annual or TDV accounting for either crawl space or attic ducts. Similarly, a comparison of the costs for R-4.2 to R-8 with the total savings in Table 3 and Table 5 shows that the upgrade f to R-8 is also cost effective in the same climate zones. Based on this analysis, we propose making R-8 ducts the prescriptive package D requirement for all ducts in unconditioned spaces in those zones. Note that for simplicity this analysis does not included any added labor costs for installing the larger ducts or any savings due to reduced air conditioning equipment size.

Air Conditioning Air Flow and Fan Energy

Table 6 – Life Cycle Cooling Energy Cost Savings for Reducing Fan Watts to 0.365 W/CFM

	Annual LCC Approach		TDV LCC Approach	
CTZ	**% of Total Source**	**$ LCC**	**TDV kBtu/ft2**	**$ LCC**
1	0%	0	0%	3
2	0%	53	1%	100
3	0%	21	1%	38
4	0%	25	1%	43
5	0%	21	1%	41
6	0%	21	1%	38
7	0%	14	1%	31
8	1%	46	1%	94
9	1%	89	2%	158
10	1%	135	2%	245
11	1%	145	2%	227
12	1%	89	1%	161
13	1%	209	2%	309
14	1%	184	2%	316
15	3%	489	3%	674
16	0%	74	1%	125

Table 7 – Life Cycle Cooling Energy Cost Savings for Reducing Fan Watts to 0.2 W/CFM

	Annual LCC Approach		TDV LCC Approach	
CTZ	**Source kBtu/ft2**	**$ LCC**	**TDV kBtu/ft2**	**$ LCC**
1	0%	4	0%	5
2	1%	117	2%	212
3	0%	43	1%	84
4	0%	57	1%	92
5	0%	46	1%	92
6	1%	46	1%	84
7	0%	32	1%	64
8	1%	99	3%	202
9	2%	188	4%	337
10	3%	287	4%	523
11	2%	308	3%	487
12	1%	191	3%	342
13	3%	450	4%	661
14	2%	397	4%	679
15	5%	1045	6%	1442
16	1%	159	2%	270

Table 6 and Table 7 show the life-cycle cooling energy savings from reducing the fan watts in the 1761 prototype house in each climate zone. Base case fan energy is set at 0.51 W/cfm based on field research which has shown that to be the average value in field testing (Proctor & Parker, 2000; Parker, 1997). We are showing the effect of two levels of efficiency. 0.365 W/cfm is the default value allowed in the DOE tests that establish the SEER ratings and should be achievable with conventional equipment carefully designed and installed. 0.2 W/cfm is a value thought to be achievable with high efficiency fan motors, efficient fans and cabinet design, good duct design, and careful installation (Sachs, 2001). Accounting is done with both the Annual LCC approach and the Time Dependant Valuation (TDV) approach. The % of Source and % of TDV gives an estimate of how significant the fan energy savings are compared to the total compliance value under the performance compliance approach. The fan savings are significant in cooling zones such as CTZ 15 where the compliance savings for a 200 W/cfm are larger than the savings from increasing duct insulation from R-4.2 to R-8.

Based on this analysis, we propose adding a new optional credit for reduced fan watts in the performance method. The standard design and the default for the proposed design will be 0.51 W/cfm. No new fan measures are required for compliance. However, builders will be allowed to specify a lower W/cfm and receive credit in their performance analysis. The magnitude of this credit will depend on the details of their proposed design. If a builder specifies reduced fan watts, the HVAC installer will be required to certify that his installation has been tested to meet the reduced watts and minimum airflow. The reduced fan watts and minimum airflow will be subject to HERS verification. ACM's will explicitly model air handler fan electricity for cooling separate from the electricity input for the compressor. The Finstall factor in the ACM manual will be adjusted from 0.852 to 0.9 because it will no longer include an adjustment for typical improper airflow.

Current ACM rules allow a credit for adequate air handler airflow in cooling that requires a Manual D duct design verified with either measured airflow or a TXV. We propose to make this credit dependant on a verified duct system design as well as on measured and verified airflow. Recent testing by PG&E has indicated that a TXV does not improve the low air performance of a cooling system so we propose to remove the airflow component of the TXV credit. The credit for a TXV or field verified charge, contained in the ACM Manual factor $F_{txv,}$ will always be 1.07. The size of the credit for adequate airflow contained in the ACM manual factor F_{equip} remains unchanged from the current rules.

Table 8 – Proposed Air Conditioner Efficiency Measures and ACM Calculation Factors

Air Conditioner Compliance Options	ACM Air Conditioning Efficiency Calculation Factors				
	F_{equip}	F_{txv}	$F_{install}$	Combined	Air Conditioning Compressor Energy Savings
No improvement or verification	0.925	1	0.9	0.83	
Adequate Airflow	1	1	0.9	0.90	8%
Adequate Charge (or TXV)	0.925	1.07	0.9	0.89	7%
Both Adequate Air Flow and Charge (TXV)	1	1.07	0.9	0.96	14%

Table 8 shows the proposed air conditioner efficiency measures and corresponding ACM calculation factors. Also shown are the overall compressor energy savings for each compliance case.

Recommendations

Proposed Standards Language

1. Modify the following section as shown:

SUBCHAPTER 8
LOW-RISE RESIDENTIAL BUILDINGS—PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

SECTION 151 – PERFORMANCE AND PRESCRIPTIVE COMPLIANCE APPROACHES

(f) **Prescriptive Standards/Alternative Component Packages**

10. **Space conditioning ducts.** All supply ducts shall either be in conditioned space or be insulated to a minimum installed level of R-4.2 and constructed to meet minimum mandatory requirements of Section 150(m). Where Tables 1-Z1 through 1-Z16 require R-8 duct insulation all ducts outside of the insulated envelope shall be insulated to R-8.

2. Add a row to Tables 1-Z1 through 1-Z5 and 1Z9 through 1Z16 as follows:

TABLE 1-Zxx—ALTERNATIVE COMPONENT PACKAGES FOR CLIMATE ZONE 14

COMPONENT			D
SPACE CONDITIONING DUCTS			
Duct sealing			REQ *
Duct Insulation			R-8

3. Add a new requirement to the standards as follows:

SUBCHAPTER 7

LOW-RISE RESIDENTIAL BUILDINGS—MANDATORY FEATURES AND DEVICES

SECTION 150 – MANDATORY FEATURES AND DEVICES

(m) **Air-distribution System Ducts, Plenums, and Fans.**

10. Porous Inner Core Flex Duct Flexible ducts having porous inner cores shall not be used.

Proposed ACM Manual Language

Modify the text in section:

2.1

HVAC Systems. This listing provides data on the heating and cooling systems in the building. These data are identical to those in the Computer Method Summary (Report C-2R) under "HVAC Systems" described on Page 2-37.

HVAC SYSTEMS

System Name	System Type	Refrigerant Charge ~~and Airflow~~	Minimum Equipment Efficiency	Distribution Type and Location	Duct R-value
Zone=Living					
LowerHeat	GasFurnace	N/A	0.78 AFUE	DuctsCrawl	~~4.2~~8
LowerAC	AirCond-Split	Yes	10.0 SEER	DuctsCrawl	~~4.2~~8
Zone=Sleep					
UpperHeat	Electric	N/A	1.00 COP	Baseboard	
UpperAC	AirCond-Split	No	10.0 SEER	DuctsAttic	~~4.2~~8

- *System Name (text):* A unique name for the HVAC system
- *System Equipment (recommended descriptor):* The type of HVAC equipment. This is specified separately from the distribution type.

Permissible equipment types: Listed in Table 2-2 and Table 2-3.

In the case of *CombHydro* heating, the name of the water heating system should be identified in the previous column. When the proposed house is not air conditioned, the entry should be *NoCooling*. If more than one type of equipment is specified, each must be listed on separate rows.

- *Refrigerant Charge ~~and Airflow~~:* Whether the refrigerant charge ~~and airflow~~ is verified or a thermostatic expansion valve is included for ducted central systems. The choices are 'yes' or 'no' where "yes" means that either refrigerant charge ~~and airflow are~~ is verified or a TXV is installed. Only split system equipment (*SplitAirCond and SplitHeatPump)* can be modeled with refrigerant charge ~~and airflow~~ verification. Six equipment types can be modeled with a TXV. They are: *SplitAirCond, PkgAirCond, LrgPkgAirCond, SplitHeatPump, PkgHeatPump, LrgPkgHeatPump.* See Table 2-3 for a description of equipment.

HVAC Distribution Systems Misc. This listing details important information associated with the use of special HVAC distribution efficiency. The use of any of these features is considered to be special and must also be individually listed on the *HERS Required Verification* listing and individually verified.

HVAC DISTRIBUTION EFFICIENCY DETAILS *(Example Listing)*

System Name	Measured Duct Leakage Target (% of fan cfm / leakage cfm)[1,2]	Measured Duct Surface Area (ft^2)	~~ACCA Manual D Design~~Adequate Air Flow	Fan CFM
Primary	6%/75.6	*150*	~~*Yes*~~*Yes*	1200
Bath	n/a	*None*	~~*No*~~*No*	*n/a*

Note 1:% of fan cfm is used when the HVAC system is installed at the time of testing and is based on a supply fan capacity of 400 cfm per ton of air conditioning capacity or 21.7 cfm per 1,000 Btus/hour of furnace capacity. When the HVAC is not installed or its capacity is not known the alternate leakage target reported is calculated from 6% of 0.70 cfm per square foot of conditioned floor area for Climate Zones 8 to 15 and 0.50 cfm per square foot of conditioned floor area for the remaining Climate Zones. For an 1800 square foot house in Climate Zone 13 (example shown above) the maximum duct leakage when system capacity is unknown is 75.6 cfm at 25 pascals.

Note 2: The HERS Required Verification listings must include the information specified in Note 1 or the results of those calculations as the method of reporting the appropriate target values for the reduced duct leakage test.

- *System Name (text):* Descriptive name corresponding to a system name defined in the HVAC System listing.

- *Measured Duct Leakage Target (% of fan cfm/leakage cfm):* Reduced duct leakage has been modeled to determine seasonal duct efficiency. This credit requires site diagnostic testing by a certified HERS rater supervised by a Commission-approved HERS provider tested in accordance with the procedures in Appendix F. The test results must be less than 6% of fan cfm (derived from installed system capacity when present or from the default assumptions for duct efficiency calculations when the HVAC heating or cooling equipment is not installed) and reported by the HERS rater on a CF-6R form and verified by the local enforcement agency. The target duct leakage must be listed in the *HERS Required Verification* section.

- *~~ACCA Manual D Design~~Adequate Air Flow* *(prescribed descriptor: Yes* or *No)*: Indicates whether modeling credit for ~~ACCA Manual D duct design has been used~~adequate air flow has been used. When duct efficiency credit for ~~ACCA Manual D design~~adequate air flow is claimed, the *HERS Required Verification and the Special Features and Modeling Assumptions* listings must specify that the ~~ACCA Manual D~~duct design, layout, and calculations be submitted to the local enforcement agency and a certified HERS rater. The certified HERS rater shall verify the existence of ~~ACCA Manual D~~the duct design layout and calculations, ~~and~~ verify that the field installation is consistent with this design and verify that adequate measured air flow is achieved.~~.~~

- *Measured Duct Surface Area (ft2)*: This item is applicable only if an airflow test verifies at least 0.033 cfm/Btu rated capacity (400 cfm/12000 Btu rated capacity) (dry coil) for a refrigerant based system or 16.8 cfm per ~~rated capacity~~ 1000 Btu/hr rated capacity for a heating only furnace system~~.the entry for *ACCA Manual D Design* is "*Yes*" and~~ and a design documents the modeling of reduced duct surface area when a value other than na (not applicable) is reported. The *HERS Required* Verification listing must indicate that this total value and its subcomponent areas by location must be verified by a certified HERS rater. Moreover reduced duct sizes must still preserve adequate airflow to receive duct efficiency credit. Consequently credit for reduced duct surface area also requires that the HERS rater measure and report HVAC supply fan flow to verify ~~that the manufacturer's specified~~the fan flow, ~~consistent with the ACCA manual D design,~~ has not been impaired by reduced duct sizes. The *HERS Required Verification* listing must also indicate this requirement.

  When *Measured Duct Surface Area* is specified the *HERS Verification Listings* must report the supply duct surface area in each of four locations: *Attic/Outside, Crawlspace, Basement, Garage.* This listing must also report whether or not the basement where the ducts are located is conditioned or not.

HVAC Systems. Information is provided on the type of heating and cooling systems proposed for each zone of the building. Data in the table is organized to accommodate any type of heating or cooling system so some of the information is not applicable for all system types. When the information is not applicable, "na" is reported. Data in this table should be organized first by heating and cooling system. Note that the thermostat type is reported under "Building Zone Information" described above.

For buildings that are modeled as multiple thermal zones, the items shall be grouped for each zone and indicated with a header "Zone = <ZoneName>". The zone name used in the header should be the same as the name used in the table titled "Building Zone Information"

HVAC SYSTEMS

Equipment Type	Minimum Equipment Efficiency (or Water Heating System Name)[1]	Refrigerant Charge ~~and Airflow~~ ~~Thermostatic Expansion Valve~~	Distribution Type and Location	Duct R-value
Zone=Living				
Furnace	0.78 AFUE	N/A	DuctsCrawl	~~4.2~~8
AirCond-Split	10.0 SEER	Yes	DuctsCrawl	~~4.2~~8
Zone=Sleep				
CombHydro	Upper Floors	N/A	Baseboard	na.
AirCond-Split	10.0 SEER	No	DuctsAttic	~~4.2~~8

- *Equipment Type.* The type of heating or cooling equipment. This is specified separate from the distribution type. Required heating equipment and cooling equipment entries are listed in Table 2-2 and Table 2-3. When the proposed house is not air conditioned, the entry should be NoCooling. If more than one type of equipment is specified, they may be listed on subsequent rows.
- *Minimum Equipment Efficiency.* The minimum equipment efficiency needed for compliance. The applicable efficiency units should also be reported, for instance AFUE for furnaces and boilers, HSPF for electric heating equipment, and SEER for heat pumps (cooling) and central air conditioners. In the case of combined hydronic heating, the name of the water heating system should be identified. If equipment type is Electric (other than heat pump), an HSPF of 3.413 should be entered, except for radiant systems which use a maximum HSPF of 3.55.
- *Refrigerant Charge ~~and Airflow~~*The choices are 'yes' or 'no' where 'yes' means that either refrigerant charge ~~and airflow are~~ is verified or a TXV is installed and verified. See Section 2.1 for system types for which this credit can be claimed.

~~3.8.2~~Cooling Equipment

The installation factor ($F_{install}$), which adjusts for typical installation practice where refrigerant charge ~~and airflow are~~is not at design values, shall be 0.90~~852~~.

The refrigerant charge ~~and airflow~~ factor (F_{TXV}), which adjusts the system performance to account for the presence of a TXV, shall be 1.0 for systems without a TXV. For systems with a TXV or verified refrigerant charge, the refrigerant charge ~~and airflow~~ factor shall be 1.07. ~~for duct systems designed according to ACCA Manual D and 1.11 for all other duct systems.~~

1 "Water Heating System Name" may be omitted from heading, except when combined hydronic systems are used.

3.8.3 Refrigerant Charge ~~and Airflow~~

Proposed Design: The ACM must allow the user to enter a central ducted cooling system with a refrigerant charge ~~and airflow~~~~verification~~ measurement option. This option requires either measuring charge ~~and airflow~~ using procedures~~s~~ set forth in Appendix K (for split system equipment only) or requires the presence of a thermostatic expansion valve (TXV). These features require~~s~~ verification by the HERS rater and must be reported in the *Special Features and Modeling Assumptions and HERS Required Verification* listings on the CF-1R and C-2R.

Standard Design: ***Standard Design:*** If a split system ducted central air conditioner or heat pump (*SplitAirCond* or *SplitHeatPump*) is used for the *Proposed Design* then the cooling system used in the *Standard Design* building shall have either refrigerant charge ~~and airflow~~ measurement or be equipped with a thermostatic expansion valve if required by Package D.

Adjustments to the source seasonal energy efficiency ratio due to refrigerant charge ~~and airflow measurement~~ or thermostatic expansion valves are described in section 3.8.2.

3.8.4 Ducts and HVAC Seasonal Distribution System Efficiency for Ducted Systems

Proposed Design: As a default, HVAC ducts for ducted systems are assumed to exist and are located in the attic. Likewise, as a default, the air handler is assumed to be located in the attic. Proposed HVAC systems with a duct layout and design on the plans may locate the ducts in the crawlspace or a basement if the layout and design specify that all of the supply registers are located in the floor and show the appropriate locations for the ducts. When all of the supply registers are located in the floor or all of the supply registers are located in the ceiling, the ACM can use Table 4.1 of Appendix F to allocate the duct surface areas. If all supply registers are in the floor, but the building has both a crawlspace and a basement, the duct location may be taken as a floor area weighted average of the entries in Table 4.1 of Appendix F. If any story of a building has supply registers in both the floor and more than two feet above the floor, the duct location for that story must be modeled as 100% ducts in the attic. If the modeled duct location for a given story is not in the attic, the ACM must specify that all supply registers for that story of the building (or the whole building) are located in the floor in the *Special Features and Modeling Assumptions* listings for special verification by the local enforcement agency.

Proposed HVAC systems with a ~~complete ACCA Manual D~~duct design including the duct layout and design on the plans may allocate duct surface area in more detail in the ACM model but the distribution of duct surface areas by location must appear on the *HERS Required Verification* list for verification by a HERS rater.

In a similar fashion, the supply duct surface area (and the location of the ducts) of a~~n~~ ~~ACCA Manual D~~ designed duct system may be modeled explicitly in the ACM and receive energy efficiency credit. When a non-default supply duct surface area is modeled, the supply duct surface area is subject to verification by a HERS rater and must be listed on the *HERS Required Verification* listings. The HERS rater must also verify the existence of the ~~ACCA Manual D~~ duct design and layout and the general consistency of the actual HVAC distribution system with the design. The HERS rater must also measure and verify the fan flow and confirm that it is at least 0.033 cfm/Btu rated capacity (400 cfm/12000 Btu rated capacity) (dry coil) for a refrigerant based system or 16.8 cfm/Btu ~~per~~ rated capacity for a heating only furnace system~~consistent with the ACCA Manual D design specifications.~~

The ACM shall allow users to specify if they will be using diagnostic testing of HVAC distribution efficiency of a fully-ducted system by a HERS rater during the construction of the building to confirm the modeling of improved HVAC distribution efficiency measures such as duct leakage. The default shall be that no diagnostic testing will be done. Duct efficiency credits may not be taken and diagnostic testing may not be done on any HVAC system that uses building cavities such as plenums or a platform return. If the user does not select diagnostic testing, the ACM shall require users to input at least two (2) basic parameters to determine HVAC distribution efficiency: the total conditioned floor area of the building as specified above and the R-value of the duct insulation which may be defaulted to Package D value.~~R4.2~~. Additional data may be required to determine seasonal distribution system efficiency. The default input parameters are presented in Appendix F. If the user specifies diagnostic testing to be performed during construction, the ACM shall request the user to enter the data described in Section 4.19, *Duct Efficiency* and shall report all required measurements and the features used to achieve higher HVAC distribution efficiencies in the *HERS Required Verification* listings. When the user chooses diagnostic testing, the diagnostic testing shall be performed as described in Appendix F. Diagnostic testing must be reported in the *HERS Required Verification* listings on the CF-1R and C-2R as described in Chapter 2.

Standard Design: The standard heating and cooling system for central systems is assumed to have air distribution ducts located in an attic space, 6% total tested duct leakage, non-~~ACCA Manual D~~ designed duct system, and a radiant barrier in climate zones where required by Package D. The *Standard Design* duct insulation is determined by the ~~appropriate~~ Package D specifications for the applicable climate zone.~~. R-4.2 duct insulation is assumed for the *Standard Design* building.~~ The *Standard Design* building is assumed to have the same number of stories as the *Proposed Design* for purposes of determining the duct efficiency. HVAC distribution system efficiencies must be calculated using the algorithms and equations in Appendix F of this manual for both the *Proposed Design* and the *Standard Design*. The *Standard Design* calculation must use the default values of that procedure. For non-central HVAC systems, the *Standard Design* shall have no ducts.

New Sections to the ACM Manual

3.2.x *Fan Energy*

Proposed Design: The ACM must allow the user to specify whether or not the proposed design will take credit for reduced fan Watts. The credit for reduced fan Watts must be reported in the *Special Features and Modeling Assumptions* listings on the CF-1R and C-2R.

Standard Design: The *Standard Design* shall have 0.51 Watts/cfm.

…..

4.19 Cooling Fan Energy

~~.~~***Proposed Design***: Energy credit for reduced fan Watts may be used with approved alternative calculation methods (ACMs). Approved ACMs must be able to model standard and reduced fan energy.

Hourly fan energy for cooling only shall be calculated based on the fan watts and cooling system on time for the hour.

Fan Wh = Cooling Load * CFM/BTU * Fan Watts/CFM

Where:

Cooling Load is the current hour sensible cooling load

CFM/BTU is the airflow per BTU of sensible cooling

Fan Watts/CFM is either 0.51 Watts/CFM or the user input.

Standard Design: The *Standard Design* shall have 0.51 Watts/cfm.

Appendix X Forced Air System Fan Flow and Air Handler Fan Watt Draw

X.1 Instrumentation Specifications

The instrumentation for the air distribution diagnostic measurements shall conform to the following specifications:

X.1.1 Pressure Measurements

All pressure measurements shall be measured with measurement systems (i.e., sensor plus data acquisition system) having an accuracy of ± 0.2 Pa. All pressure measurements within the duct system shall be made with static pressure probes.

X.1.2 Fan Flow Measurements

All measurements of distribution fan flows shall be made with measurement systems (i.e., sensor plus data acquisition system) having an accuracy of ± 7% reading or ± 5 cfm whichever is greater.

X.1.3 Watt Measurements

All measurements of air handler watt draws shall be made with measurement systems (i.e., sensor plus data acquisition system) having an accuracy of ± 1% reading or ± 5 watts whichever is greater.

X.2 Apparatus

X.2.1 System Fan Flows

HVAC system fan flow shall be measured using one of the following methods.

X.2.1.1 Plenum Pressure Matching Measurement

The apparatus for measuring the system fan flow shall consist of a duct pressurization and flow measurement device (subsequently referred to as a fan flowmeter) meeting the specifications in X.1.2, a static pressure transducer meeting the specifications in Section X.1.1, and an air barrier between the return duct system and the air handler inlet. The measuring device shall be attached at the air handler blower compartment door. All registers shall be in their normal operating condition. The static pressure probe shall be fixed to the supply plenum so that it is not moved during this test.

X.2.1.2 Flow Capture Hood Measurement

A flow capture hood meeting the specifications in section X.1.2. can be used to verify the fan flow at the return register(s) after the completion of a rough-in duct leakage measurement. All registers shall be in their normal operating position. Measurement(s) shall be taken at the return grill(s).

X.2.1.3 Flow Grid Measurement

The apparatus for measuring the system fan flow shall consist of a flow measurement device (subsequently referred to as a fan flow grid) meeting the specifications in X.1.2 and a static pressure transducer meeting the specifications in Section X.1.1. The measuring device shall be attached at a point where all the fan airflow shall flow through the flowgrid . All registers shall be in their normal operating condition. The static pressure probe shall be fixed to the supply plenum so that it is not moved during this test.

X.2.2 Air Handler Watts

The Air Handler watt draw shall be measured using one of the following methods.

X.2.2.1 Portable Watt Meter Measurement

The apparatus for measuring the air handler watt draw shall consist of a watt meter meeting the specifications in XXXX.1.3. The measuring device shall be attached to measure the air handler fan watt draw. All registers shall be in their normal operating condition.

X.2.2.2 Utility Revenue Meter Measurement

The apparatus for measuring the air handler watt draw shall consist of the utility revenue meter meeting the specifications in X.1.3 and a stop watch measuring in seconds. The revenue meter shall be configured to measure only the air handler watt draw. All registers shall be in their normal operating condition.

X.3 Procedure

To obtain airflow credit a diagnostic fan flow measurement must be performed and ~~a~~ the duct system must be designed.

To obtain airflow and fan watt draw credit. a diagnostic fan flow measurement must be performed, the ~~a~~ duct system must be designed, and the air handler fan watt draw measurement must be performed.~~,~~

x.3.1 Diagnostic Fan Flow

The diagnostic fan flow shall be measured using one of the following methods:

x.3.1.1 Diagnostic Fan Flow Using Flow Capture Hood

The fan flow measurement shall be performed using the following procedures;~~:,~~ all registers shall be fully open, and the air filter shall be installed. Turn on the system fan at the maximum speed used in the installation (usually the cooling speed when air conditioning is present) and measure the fan flow at the return grille(s) with a calibrated flow capture hood to determine the total system return fan flow. The system fan flow (Qah, cfm) shall be the sum of the measured return flows.

x.3.1.2 Diagnostic Fan Flow Using Plenum Pressure Matching

The fan flow measurement shall be performed using the following procedures:

1. With the system fan on at the maximum speed used in the installation (usually the cooling speed when air conditioning is present), measure the pressure difference (in pascal) between the supply plenum and the conditioned space (~~.~~Psp). Psp is the target pressure to be maintained during the fan flow tests. If there is no access to the supply plenum, then place the pressure probe in the nearest supply duct. Adjust the probe to achieve the highest pressure and then firmly attach the probe (e.g., with duct tape) to ensure that it does not move during the fan flow test.

2. Block the return duct from the plenum upstream of the air handler fan and the fan flowmeter. Filters are often located in an ideal location for this blockage.

3. Attach the fan flowmeter device to the duct system at the air handler. For many air handlers, there will be a removable section that allows access to the fan that is suitable for this purpose.

4. ~~.~~ If the fan flowmeter is connected to the air handler outside the conditioned space, then the door or access panel between the conditioned space and the air handler location shall be opened.

5. Turn on the system fan and the fan flowmeter, adjust the fan flowmeter until the pressure between supply plenum and conditioned space matches Psp.

6. Record the flow through the flowmeter (Qah, cfm) - this is the diagnostic fan flow. In some systems, typical system fan and fan flowmeter combinations may not be able to produce enough flow to reach Psp. In this case record the maximum flow (Qmax, cfm) and pressure (Pmax) between the supply plenum and the conditioned space. The following equation shall be used to correct measured system flow and pressure (Qmax and Pmax) to operating condition at operating pressure (Psp).

Equation (X.1) Air Handler Flow Qah = Qmax X (Psp/Pmax) ^.5

X.3.1.3 Diagnostic Fan Flow Using Flow Grid Measurement

The fan flow measurement shall be performed using the following procedures:

1. With the system fan on at the maximum speed used in the installation (usually the cooling speed when air conditioning is present measure the pressure difference (in pascal) between the supply plenum and the conditioned space (Psp). If there is no access to the supply plenum, then place the pressure probe in the nearest supply duct. Adjust the probe to achieve the highest pressure and then firmly attach the probe (e.g., with duct tape) to ensure that it does not move during the fan flow test

2. The flow grid shall be attached at a point where all the fan air flows through the flow grid.

3. Re-measure the system operating pressure with the flow grid in place.

4. Measure the air flow through the flow grid (Qgrid) and the test pressure (Ptest).

5. The following equation shall be used to correct flow through the flow grid and pressure (Qgrid and Ptest) to operating condition at operating pressure (Psp).

Equation (X.2) Air Handler Flow

Qah = Qmax X (Psp/Ptest) ^.^{5}

X.3.2 Duct Design

The duct system shall be designed within two constraints, the air flow rate and the available external static pressure from the air handler at that airflow. The duct design shall have calculations showing the duct system will operate at equal to or greater than 0.0375 cfm/Btu rated capacity (450 cfm/12000 Btu rated capacity) in cooling speed (dry coil) or, if heating only, equalt to or greater than 16.8 cfm per 1000 Btu/hr furnace output. The design shall be based on the available external static pressure from the air handler, the pressure drop of external devices, the equivalent length of the runs, as well as the size, type and configuration of the ducts. The duct layout shall be included on the plans and the duct design shall be reported on the CF-6R and posted on-site.

X.3.3 Diagnostic Air Handler Watt Draw

The diagnostic air handler watt draw shall be measured using one of the following methods:

Diagnostic Air Handler Watt Draw Using Portable Watt Meter

The air handler watt draw measurement shall be performed using the following procedures~~:~~; all registers shall be fully open, and the air filter shall be installed. Turn on the system fan at the maximum speed used in the installation (usually the cooling speed when air conditioning is present) and measure the fan watt draw (Wfan).

Diagnostic Air Handler Watt Draw Using Utility Revenue Meter

The air handler watt draw measurement shall be performed using the following procedures; all registers shall be fully open, and the air filter shall be installed. Turn on the system fan at the maximum speed used in the installation (usually the cooling speed when air conditioning is present) and turn off every circuit breaker except the one exclusively serving the air handler. Record the Kh factor on the revenue meter, count the number of full revolutions of the meter wheel over a period exceeding 90 seconds. Record the number of revolutions (Nrev) and time period (trev, seconds). Compute the air handler watt draw (Wfan) using the following formula:

Equation X.3 .Air Handler Fan Watt Draw $W_{fan} = (K_h \times N_{rev} \times 3600) / t_{rev}$

Return all circuit breakers to their original positions.

Appendix F

Standard Procedure for Determining the Seasonal Energy Efficiencies of Residential Air Distribution Systems

1.0 Introduction

This appendix describes the measurement and calculation methods for determining air distribution system efficiency.

2.0 Definitions

aerosol sealant closure system: A method of sealing leaks by blowing aerosolized sealant particles into the duct system and which must include minute-by-minute documentation of the sealing process.

floor area :The floor area of enclosed conditioned space on all floors of a building, as measured at the floor level of the exterior surfaces enclosing the conditioned space.

delivery effectiveness :The ratio of the thermal energy delivered to the conditioned space and the thermal energy entering the distribution system at the equipment heat exchanger.

distribution system efficiency :The ratio of the thermal energy consumed by the equipment with the distribution system to the energy consumed if the distribution system had no losses or impact on the equipment or building loads.

equipment efficiency :The ratio between the thermal energy entering the distribution system at the equipment heat exchanger and the energy being consumed by the equipment.

equipment factor : F_{equip} is the ratio of the equipment efficiency ~~including~~ with the effects of reduced air flow ~~of the distribution system~~ to the equipment efficiency of the equipment i~~n isolation~~ with proper air flow.

fan flowmeter device*:* A device used to measure air flow rates under a range of test pressure differences.

flow capture hood**:** A device used to capture and measure the airflow at a register.

load factor : F_{load} is the ratio of the building energy load without including distribution effects to the load including distribution system effects.

pressure pan : a device used to seal individual forced air system registers and to measure the static pressure from the register.

radiant barrier : a surface of low emissivity (less than 0.05) placed inside an attic or roof space to reduce radiant heat transfer.

recovery factor : F_{recov} is the fraction of energy lost from the distribution system that enters the conditioned space.

thermal regain: The fraction of delivery system losses that are returned to the building.

3.0 Nomenclature

a_r = duct leakage factor (1-return eakage) for return ducts

a_s = duct leakage factor (1-supply leakage)p for supply ducts

A_{floor} = conditioned floor area of building , ft^2

$A_{r,out}$ = surface area of return duct outside conditioned space ,ft^2

$A_{r,attic}$ = return duct area in attic , ft^2

$A_{r,base}$ = return duct area in basement , ft^2

$A_{r,crawl}$ = return duct area in crawlspace, ft^2

$A_{r,gar}$= return duct area inside garage, ft^2

$A_{s,out}$ = surface area of supply duct outside conditioned space,ft^2

$A_{s,attic}$ = supply duct area in attic , ft^2

$A_{s,base}$ = supply duct area in basement , ft^2

$A_{s,crawl}$ = supply duct area in crawlspace,ft^2

$A_{s,gar}$ = supply duct area inside garage, ft^2

$A_{s,in}$ = supply duct area inside conditioned space, ft^2

B_r = conduction fraction for return

B_s = conduction fraction for supply

DE = delivery effectiveness_

DE_{design} = design delivery effectiveness

$DE_{seasonal}$ = seasonal delivery effectiveness

E_{equip} = rate of energy exchanged between equipment and delivery system, Btu/hour

~~$F_{cycloss}$ = cyclic loss factor~~

F_{equip} = l~~oad factor for equipment~~system air flow factor

~~F_{flow} = load factor for fan flow effect on equipment efficiency~~

~~F_{leak} = fraction of system fan flow that leaks out of supply or return ducts~~

F_{load} = load factor for delivery system

F_{recov} = thermal loss recovery factor

F_{regain} = thermal regain factor

K_r = return duct surface area coefficient

K_s = supply duct surface area coefficient

N_{story} = number of stories of the building

P_{sp} = pressure difference between supply plenum and conditioned space [Pa]

P_{test} = test pressure for duct leakage [Pa]

Q_e = Flow through air handler fan at operating conditions, cfm

$Q_{total,25}$ = total duct leakage at 25 Pascal, cfm

R_r = thermal resistance of return duct, h ft^2 F/Btu

R_s = thermal resistance of supply duct, h ft^2 F/Btu

$T_{amb,r}$ = ambient temperature for return , F

$T_{amb,s}$ = ambient temperature for supply , F

T_{attic} = attic air temperature , F

T_{base} - return duct temperature in basement, F

T_{crawl} - return duct temperature in crawlspace,F

T_{design} = outdoor air design temperature , F

T_{ground} = ground temperature , F

T_{gar} = temperature of garage air , F

T_{in} = temperature of indoor air , F

T_{rp} = return plenum air temperature , F

$T_{seasonal}$ = outdoor air seasonal temperature, F

T_{sp} = supply plenum air temperature , F

ΔT_e = temperature rise across heat exchanger , F

ΔT_r = temperature difference between indoors and the ambient for the return , F

ΔT_s = temperature difference between indoors and the ambient for the supply,

$\eta_{dist,seasonal}$ = seasonal distribution system efficiency

4.0 Air Distribution Diagnostic Measurement and Default Assumptions

4.1 Instrumentation Specifications

The instrumentation for the air distribution diagnostic measurements shall conform to the following specifications:

4.1.1 Pressure Measurements

All pressure measurements shall be measured with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of ± 0.2 Pa. All pressure measurements within the duct system shall be made with static pressure probes.

~~4.1.2 Fan Flow Measurements~~

~~All measurements of distribution fan flows shall be made with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of ±5% reading or ±5 cfm whichever is greater.~~

4.1.2~~3~~ Duct Leakage Measurements

The measurement of airflows during duct leakage testing shall have an accuracy of ±3% of measured flow using digital gauges.

All instrumentation used for ~~fan flow and~~ duct leakage diagnostic measurements shall be calibrated according to the manufacturer's calibration procedure to conform to the above accuracy requirement. All testers performing diagnostic tests shall obtain evidence from the manufacturer that the equipment meets the accuracy specifications. The evidence shall include equipment model, serial number, the name and signature of the person of the test laboratory verifying the accuracy, and the instrument accuracy. All diagnostic testing equipment is subject to re-calibration when the period of the manufacturer's guaranteed accuracy expires.

4.2 Apparatus

~~4.2.1 System Fan Flows~~

~~HVAC system fan flow shall be measured using one of the following methods.~~

~~4.2.1.1 Plenum pressure matching measurement~~

~~The apparatus for measuring the system fan flow shall consist of a duct pressurization and measurement device (subsequently referred to as a fan flowmeter [see section 4.3.7.2.2.]) meeting the specifications in 4.1.3, a static pressure transducer meeting the specifications in Section 4.1.1, and an air barrier between the return duct system and the air handler inlet. The measuring device shall be attached at the air handler blower compartment door. All registers shall be in their normal operating condition. The static pressure probe shall be fixed to the supply plenum so that it is not moved during this test.~~

~~4.2.1.2 Flow hood measurement~~

~~A flow hood meeting the specifications in section 4.1.2. can be used to verify the fan flow at the return register(s) after the completion of a rough-in duct leakage measurement. All registers shall be in their normal operating position. Measurement(s) shall be taken at the return grill(s).~~

4.2.1~~2~~ Duct Leakage

The apparatus for fan pressurization duct leakage measurements shall consist of a duct pressurization and flow measurement device meeting the specifications in Section 4.1.3.

4.3 Procedure

The following sections identify input values for building and HVAC system (including ducts) using either default or diagnostic information.

4.3.1 Building Information

The calculation procedure for determining air distribution efficiencies requires the following building information:

- ~~1.~~climate zone for the building,
- ~~2.~~conditioned floor area,
- ~~3.~~number of stories,
- ~~4.~~supply duct location and
- ~~5.~~floor type.

4.3.1.1 Default Input

Using default values rather than diagnostic procedures produce relatively low air distribution-system efficiencies. Default values shall be obtained from following sections:

1. the location of the duct system in Section 4.3.4,
2. the surface area and insulation level of the ducts in Sections 4.3.3, 4.3.4 and 4.3.6,
3. the system fan flow in Section 4.3.7, and
4. the leakage of the duct system in Section ~~4.3.8~~4.3.7.

4.3.2 Diagnostic Input

Diagnostic inputs are used for the calculation of improved duct efficiency. The diagnostics include observation of various duct characteristics and measurement of duct leakage ~~and system fan flows~~ as described in Sections 4.3.5 through 4.3.7~~8~~. These observations and measurements replace those assumed as default values.

The diagnostic procedures include

- measure supply duct surface area as described in Section 4.3.3.2.
- measure total duct system leakage as described in Section ~~4.3.8~~4.3.7.

- ~~measure system fan flow or observe the presence of a thermostatic expansion valve for claiming ACCA manual D design credit as described in Section 4.3.7.~~
- Observe the insulation level for the supply (R_s) and return (R_r) ducts outside the conditioned space as described in Section 4.3.6.
- Observe the presence of radiant barriers.

4.3.3 Duct Surface Area

The supply-side and return-side duct surface areas shall be calculated separately. If the supply or return duct is located in more than one zone, the area of that duct in each zone shall be calculated separately. The duct surface area shall be determined using the following methods.

4.3.3.1 Default Duct Surface Area

4.3.3.1.1 Duct Surface Area for More Than 12 feet of Duct Outside Conditioned Space

The default duct surface area for supply and return shall be calculated as follows:

For supplies:

$$A_{s,total} = 0.27 A_{floor} \quad (4.1)$$

For returns:

$$A_{r,total} = K_r \; A_{floor} \quad (4.2)$$

Where K_r (return duct surface area coefficient) shall be 0.05 for one story building and 0.1 for two or more stories.

4.3.3.1.1 Duct Surface Area for Less Than 12 feet of Duct Outside Conditioned Space

For HVAC systems with air handlers located outside the conditioned space but with less than 12 feet of duct located outside the conditioned space including air handler and plenum, the duct surface area outside the conditioned space shall be calculated as follows:

$$A_{s,out} = 0.027 \; A_{floor} \quad (4.3)$$

Where $A_{s,out}$ is substituted for $A_{s,attic}$; $A_{s,crawl}$; or $A_{s,base}$ depending on the location of the ducts.

4.3.3.2 Diagnostic Duct Surface Area

A well designed duct system can reduce the length of the supply duct. Smaller duct surface area will result in reduced duct conduction losses. Duct surface area shall be calculated from measured duct lengths and nominal outside diameters (for round ducts) or outside perimeters (for rectangular ducts) of each duct run in the building. Improved conduction losses can be claimed for reduced supply duct surface area only (it does not apply to the return duct). Supply plenum surface area shall be included in the supply duct surface area. Diagnostic duct surface area requires measuring duct surface areas separately for each location outside conditioned space ($A_{s,attic}$; $A_{s,crawl}$; or $A_{s,base}$) and the system fan flow using the methods in Appendix X- to ensure that there is sufficient air flow to deliver the designed heating and cooling loads. The measured fan flow must exceed 0.0375 cfm/Btu rated capacity (450 cfm/12000 Btu rated capacity) (dry coil) for all systems with refrigerated cooling. The measured fan flow must exceed 16.8 cfm per 1000 Btu/hr -rated capacity for a heating only furnace-system. Measuring the airflow may also qualify the system for an airflow credit.

4.3.4 Duct Location

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses. Default duct surface areas by locations of the supply duct shall be obtained from Table 4.1. The default duct surface area for crawlspace and basement applies only to buildings with all supply ducts installed in the crawlspace or basement. If the supply duct is installed in locations other than crawlspace or basement, the default supply duct location shall be "Other".

If ducts are installed in multiple locations, air distribution efficiency shall be calculated for each duct location. Total air distribution efficiency for the house shall be the weighted average based on the floor area served by each duct system.

Table 4.1 Default Assumptions for Duct Locations

	Supply Duct Surface Area		**Return Duct Surface Area**	
Supply or Return Duct Location	One story	Two or more story	One story	Two or more story
Attic	100% attic	65% attic 35% conditioned space	100% attic	100% attic
Crawlspace	100% crawlspace	65% crawlspace 35% conditioned space	100% attic	100% attic
Basement	100% Basement	65% basement 35% conditioned space	100% Basement	100% Basement
Other	100% attic	65% attic 35% conditioned space	100% attic	100% attic

4.3.5 Climate and Duct Ambient Conditions for Ducts Outside Conditioned Space

Duct ambient temperature for both heating and cooling at different duct locations shall be obtained from Table 4.2. Indoor dry-bulb (T_{in}) temperature for cooling is 78°F. The indoor dry-bulb temperature for heating is 70°F. Reduction of attic temperature and the reduction in solar radiation effect due to radiant barriers shall only be applied to cooling calculations. The procedures for the installation of radiant barriers shall be as described in ACM Section 4.23. Attic temperatures for houses with radiant barriers shall be obtained from Table 4.2.

Table 4.2 Default Assumptions for Duct Ambient Temperature

	Duct Ambient Temperature for Heating, $T_{heat,amb}$			Duct Ambient Temperature for Cooling, $T_{cool,amb}$				
Climate zone	Attic	Crawlspace	Basement	Attic	Attic w/ radiant barrier (supply)	Attic w/ radiant barrier (return)	Crawlspace	Basement
1	52.0	52.2	48.9	60.0	65.4	61.2	54.0	49.1
2	48.0	48.7	56.5	87.0	84.3	84.2	78.0	64.5
3	55.0	54.9	58.3	80.0	79.4	78.2	71.8	62.8
4	53.0	53.1	56.6	79.0	78.7	77.4	70.9	61.4
5	49.0	49.6	52.3	74.0	75.2	73.1	66.4	56.8
6	57.0	56.7	59.9	81.0	80.1	79.1	72.7	64.1
7	62.0	61.1	60.4	74.0	75.2	73.1	66.4	61.6
8	58.0	57.6	60.1	80.0	79.4	78.2	71.8	63.9
9	53.0	53.1	59.6	87.0	84.3	84.2	78.0	66.4
10	53.0	53.1	61.1	91.0	87.1	87.6	81.6	68.9
11	48.0	48.7	59.5	95.0	89.9	91.0	85.1	69.5
12	50.0	50.4	59.3	91.0	87.1	87.6	81.6	67.8
13	48.0	48.7	58.4	92.0	87.8	88.4	82.4	67.6
14	39.0	40.7	55.4	99.0	92.7	94.4	88.7	68.6
15	50.0	50.4	63.4	102.	94.8	96.9	91.3	74.6
16	32.0	34.4	43.9	80.0	79.4	78.2	71.8	54.1

4.3.6 Duct Wall Thermal Resistance

4.3.6.1 Default Duct Insulation R value

Default duct wall thermal resistance is R4.2. An air film resistance of 0.7 [h ft^2 ^oF/BTU] shall be added to the duct insulation R value to account for external and internal film resistance.

4.3.6.2 Diagnostic Duct Wall Thermal Resistance

Duct wall thermal resistance shall be determined from the manufacturer's specification observed during diagnostic inspection. If ducts with multiple R values are installed, the lowest duct R value shall be used. If a duct with a higher R value than 4.2 is installed, the R-value shall be clearly stated on the building plan and a visual inspection of the ducts must be performed to verify the insulation values. In case the space on top of the duct boot is limited and can not be inspected, the insulation R value within two feet of the boot to which the duct is connected may be excluded from the determination of the overall system R value.

4.3.7 ~~System Fan Flow~~

~~4.3.7.1~~ Default System Fan Flow

The default cooling fan flow with an air conditioner and for heating with a heat pump for **climate zones 8 through 15** shall be calculated as follows:

$$Q_e = 0.70\ A_{floor} \quad (4.4)$$

The default cooling fan flow with an air conditioner and for heating with a heat pump for **climate zones 1 through 7 and 16** and default heating fan flow for forced air furnaces for all climate zones shall be calculated as follows:

$$Q_e = 0.50\ A_{floor} \quad (4.5)$$

~~4.3.7.2 Diagnostic Fan Flow~~

~~To obtain duct efficiency credit for duct systems designed according to ACCA Manual D, a diagnostic fan flow measurement must be performed or the installation of a thermostatic expansion valve must be verified. The access panel on the cooling coil shall be removable for the verification of a thermostatic expansion valve. For ACCA Manual D designed duct system, engineering calculations and the building plan for duct sizing and layout shall also be prepared. The diagnostic fan flow measurement shall be measured using one of the following methods:~~

~~4.3.7.2.1 Diagnostic Fan Flow Using Flow Hood:~~

~~To measure the system return fan flow, all registers shall be fully open, and the air filter shall be installed. Turn on the system fan and measure the fan flow at the return grille(s) with a calibrated flow hood to determine the total system return fan flow. The system fan flow (Q_e) shall be the sum of the measured return flows.~~

~~4.3.7.2.2 Diagnostic Fan Flow Using Plenum Pressure Matching:~~

~~The fan flow measurement shall be performed using the following procedures:~~

1. ~~With the system fan on (in heating mode with burners on for heating, or in cooling mode with compressor on), measure the pressure difference (in pascal) between the supply plenum and the conditioned space (ΔP_{sp}). P_{sp} is the target pressure to be maintained during the fan flow tests. If there is no access to the supply plenum, then place the pressure probe in the nearest supply duct. Adjust the probe to achieve the highest pressure and then firmly attach the probe (e.g., with duct tape) to ensure that it does not move during the fan flow test.~~

~~2. Block the return duct from the plenum upstream of the air handler fan and the fan flowmeter. Filters are often located in an ideal location for this blockage.~~

~~3. Attach the fan flowmeter device to the duct system at the air handler. For many air handlers, there will be a removable section that allows access to the fan that is suitable for this purpose. Assure that there is no significant leakage between the fan flowmeter and the system fan.~~

~~4. If the fan flowmeter is connected to the air handler outside the conditioned space, then the door or access panel between the conditioned space and the air handler location shall be opened.~~

~~5. Turn on the system fan and the fan flowmeter, adjust the fan flowmeter until the pressure between supply plenum and conditioned space matches~~ ~~P_{sp}.~~

~~6. Record the flow through the flowmeter~~ ~~(Q_e, cfm) - this is the diagnostic fan flow.~~

~~In some systems, typical system fan and fan flowmeter combinations may not be able to produce enough flow to reach~~ ~~P_{sp}. In this case record the maximum flow (Q_{max}, cfm) and pressure (P_{max}) between the supply plenum and the conditioned space. The following equation shall be used to correct measured system flow and pressure (Q_{max} and P_{max}) to operating condition (Q_e) at operating pressure (P_{sp}).~~

$$\cancel{Q_e = Q_{max}\left(\frac{P_{sp}}{P_{max}}\right)^{\frac{1}{2}}} \qquad \cancel{(4.6)}$$

4.3.8 Duct Leakage

4.3.8.1 Duct Leakage Factor for Delivery Effectiveness Calculations

Default duct leakage factors shall be obtained from Table 4.3, using the "not Tested" values.

Duct leakage factors shown in Table 4.3 shall be used in calculations of delivery effectiveness.

Table 4.3 Duct Leakage Factors

	Duct Leakage Diagnostic Test Performed using Section 4.3.8.2 Procedures	$a_s = a_r =$
Duct systems in homes built prior to 1999	Not tested	0.86
Duct systems in homes built after 1999	Not tested	0.89
Duct systems in homes of all ages, System with refrigerant based cooling, tested after house and HVAC system completion	(Q_{25}) Total leakage is less than 0.06 Q_{ecool}	0.96
Duct systems in homes of all ages, System without refrigerant based cooling, tested after house and HVAC system completion	(Q_{25}) Total leakage is less than 0.06 Q_{eheat}	0.96
Duct systems with refrigerant based cooling, in homes built after 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.06 Q_{ecool} and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built after 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.06 Q_{eheat} and final duct integrity verified	0.96
Duct systems with refrigerant based cooling, in homes built after 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.04 Q_{ecool} and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built after 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.04 Q_{eheat} and final duct integrity verified	0.96

4.3.8.2 Diagnostic Duct Leakage

Diagnostic duct leakage measurement is used to quantify total leakage for the calculation of air distribution efficiency. To obtain the improved duct efficiency for sealing the duct system, a diagnostic leakage test as described in section 4.3.8.2.1 or 4.3.8.2.2 must be performed. Houses built after 1/1/1999 shall not be allowed to claim duct leakage credit and diagnostic testing may not be done on any HVAC system that uses building cavities such as plenums or a platform return.

4.3.8.2.1 Diagnostic Duct Leakage from Fan Pressurization of Ducts

The total duct leakage shall be determined by pressurizing the ducts to 25 Pascals. The following procedure shall be used for the fan pressurization tests:

1. Seal all the supply and return registers, except for one return register or the system fan access.
2. Attach the fan flowmeter device to the duct system at the unsealed register or access door.
3. Install a static pressure probe at a supply.
4. Adjust the fan flowmeter to produce a 25 Pascal (0.1 in water) pressure difference between the supply duct and the outside or the building space with the entry door open to the outside.
5. Record the flow through the flowmeter ($Q_{total,25}$) - this is the total duct leakage flow at 25 Pascals.

When the diagnostic leakage test is performed and the measured total duct leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table 4.3.

4.3.8.2.2 Diagnostic Duct Leakage at Rough-in Construction Stage Using An Aerosol Sealant Closure System

Duct leakage in new construction may be determined by using diagnostic measurements at the rough-in building construction stage prior to installation of the interior finishing wall when using an aerosol sealant closure system. When using this measurement technique, additional verification (as described in section 4.3.8.2.2.3) of duct integrity shall be completed after the finishing wall has been installed. In addition, after the finishing wall is installed, spaces between the register boots and the wallboard shall be sealed. Cloth backed rubber adhesive duct tapes shall not be used to seal the space between the register boot and the wall board.

The duct leakage measurement at rough-in construction stage shall be performed using a fan pressurization device. The duct leakage shall be determined by pressurizing both the supply and return ducts to 25 Pa. The procedures in Sections 4.3.8.2.2.1 and 4.3.8.2.2.2 shall be used for measuring duct leakage before the interior finishing wall is installed.

4.3.8.2.2.1 For ducts with the air handling unit installed and connected:

For total leakage:

1. Verify that supply and return plenums and all the connectors, transition pieces and duct boots have been installed. If a platform is used as part of the air distribution system, it must contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test.

2. Seal all the supply duct boots and return boxes except for one return duct box.

3. Attach the fan flowmeter device at the unsealed duct box.

4. Insert a static pressure probe at one of the sealed supply duct boots.

5. Adjust the fan flowmeter to maintain 25 Pa (0.1 in water)between the duct system and outside or the building space with the entry door open to the outside.

6. Record the air flow through the flowmeter ($Q_{total,25}$) - This is the total duct leakage at 25 Pa at rough-in stage.

7. Divide the measured total leakage by the total fan flow calculated from equation 4.4 or 4.5.

If the total leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table 4.3.

4.3.8.2.2.2 For ducts with air handling unit not yet installed:

For total leakage:

1. Verify that all the connectors, transition pieces and duct boots have been installed. If a platform is used as part of the air distribution system, it must contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test.

2. Use a duct connector to connect supply and/or return duct box to the fan flowmeter. Supply and return leaks may be tested separately. If there is only one return register, the supply and return leaks shall be tested at the same time.

3. Seal all the supply duct boots and/or return boxes except for one supply or return duct box.

4. Attach the fan flowmeter device at the unsealed duct box.

5. Insert a static pressure probe at one of the sealed supply duct boots.

6. Adjust the fan flowmeter to maintain 25 Pa (0.1 in water) between the building conditioned space and the duct system.

7. Record the air flow through the flowmeter ($Q_{total,25}$) - This is the total duct leakage at 25 Pa.

8. Divide the measured total leakage by the total fan flow calculated from equation 4.4 or 4.5. If the total leakage is less than 4% of the total fan flow, the total duct leakage factor shall be 0.96 as shown in Table 4.3.

4.3.8.2.2.3 Post rough-in duct leakage verification

After installing the interior finishing wall and verifying that one of the above rough-in tests was completed, one of the following post rough-in verification tests shall be performed to ensure that there is no major leakage in the duct system.

4.3.8.2.2.3.1 Visual inspection

Remove at least one supply and one return register to verify that the spaces between the register boot and the interior finishing wall are properly sealed. In addition, if the house rough-in duct leakage test was conducted without an air handler installed, inspect the connection points between the air handler and the supply and return plenums to verify that the connection points are properly sealed. All joints shall be inspected to ensure that no cloth backed rubber adhesive duct tape is used.

4.3.8.2.2.3.2 Pressure pan test

With register dampers fully open, the house is pressurized to 25 pascals by a blower door, (If two registers are within 5 feet of each other and are connected to the same duct run, one register shall be sealed off before the pressure pan test is performed). the pressure difference across each register shall not exceed 1.5 Pa.

4.3.8.2.2.3.3 House Pressure Test

The pressure difference between the building conditioned space and a vented attic shall be measured to determine whether the house pressure is changed appreciably by the operation of the air handler. To perform this test, the pressure difference (P_{house}- P_{out}) between the building conditioned space and a vented attic (or outside if impossible to access the attic), shall be measured four times:

1. with the fan off (ΔP_{off1})

2. with the fan on (ΔP_{on})

3. with the fan on and the return grille 80% blocked (ΔP_{RB}). Block 80% on all return grilles if the house has two or more returns.

4. with the fan off (ΔP_{off2})

For each of these measurements, the five-second average pressure shall be measured 10 times and these 10 measurements shall be averaged.

For the house to pass this test, the following conditions must be true:

1. $\Delta P_{on} -(\Delta P_{off2}+\Delta P_{off1})/2$ must be between +0.8 Pa and -0.8 Pa and

2 $\Delta P_{RB} - \Delta P_{on}$ must be less than 0.8 Pa.

In addition, the absolute value of ($\Delta P_{off2} - \Delta P_{off1}$) must be less than 0.25 Pa, or else the test must be repeated. If the repeated test does not meet the above specified values, visual inspection or the pressure pan test or the fan pressurization test must be used. If these tests fail, the duct system needs to be properly sealed and re-verified by a fan pressurization test.

4.4 Delivery Effectiveness (DE) Calculations

Seasonal delivery effectiveness shall be calculated using the seasonal design temperatures from Tables 4.2.

4.4.1 Calculation of Duct Zone Temperatures

The temperatures of the duct zones outside the conditioned space are determined in Section 4.3.5 for seasonal conditions for both heating and cooling. If the ducts are not all in the same location, the duct ambient temperature for use in the delivery effectiveness and distribution system efficiency calculations shall be determined using an area weighted average of the duct zone temperatures:

$$T_{amb,s} = \frac{(A_{s,attic} + 0.001)\,T_{attic} + A_{s,crawl}\,T_{crawl} + A_{s,base}\,T_{base}}{A_{s,out} + 0.001} \quad (4.7)$$

$$T_{amb,r} = \frac{A_{r,attic}\,T_{attic} + A_{r,crawl}\,T_{crawl} + A_{r,base}\,T_{base}}{A_{r,out}} \quad (4.8)$$

The return ambient temperature, $T_{amb,r}$, shall be limited as follows:

For heating, the maximum $T_{amb,r}$ is $T_{in,heat}$. For cooling, the minimum $T_{amb,r}$ is $T_{in,cool}$.

$$T_{amb,r} = \frac{T_{design} - 16\,^{o}F + \dfrac{\sum\limits_{i=\text{duct location}}^{\substack{\text{all return duct locations}\\ \text{outside conditioned space}}} A_i\,T_i}{A_r}}{2} \quad (4.20b)$$

4.4.2 Seasonal Delivery Effectiveness (DE)

The supply and return conduction fractions, B_s and B_r, shall be calculated as follows:

$$B_s = \exp\left(\frac{-A_{s,out}}{1.08\,Q_e\;R_s}\right) \quad (4.9)$$

$$B_r = \exp\left(\frac{-A_{r,out}}{1.08\ Q_e\ R_r}\right) \quad (4.10)$$

The temperature difference across the heat exchanger in the following equation is used:
for heating:

$$\Delta T_e = 55 \quad (4.11)$$

for cooling:

$$\Delta T_e = -20 \quad (4.12)$$

The temperature difference between the building conditioned space and the ambient temperature surrounding the supply, ΔT_s, and return, ΔT_r, shall be calculated using the indoor and the duct ambient temperatures.

$$\Delta T_s = T_{in} - T_{amb,s} \quad (4.13)$$

$$\Delta T_r = T_{in} - T_{amb,r} \quad (4.14)$$

The seasonal delivery effectiveness for heating or cooling systems shall be calculated using:

$$DE_{seasonal} = a_s B_s - a_s B_s (1 - B_r a_r) \frac{\Delta T_r}{\Delta T_e} - a_s (1 - B_s) \frac{\Delta T_s}{\Delta T_e} \quad (4.15)$$

1

4.5 Seasonal Distribution System Efficiency

Seasonal distribution system efficiency shall be calculated using delivery effectiveness, equipment, load, and recovery factors calculated for seasonal conditions.

4.5.2 Thermal Regain (F_{regain})

The reduction in building load due to regain of duct losses shall be calculated using the thermal regain factor. The default thermal regain factors are provided in Table 4.4.

Table 4.4 Thermal Regain Factors	
Supply Duct Location	**Thermal Regain Factor [F_{regain}]**
Attic	0.10
Crawlspace	0.12
Basement	0.30
Other	0.10

4.5.3 Recovery Factor (F_{recov})

The recovery factor, F_{recov}, is calculated based on the thermal regain factor, F_{regain}, and the duct losses without return leakage.

$$F_{recov} = 1 + F_{regain}\left(\frac{1 - a_s B_s + a_s B_s (1 - B_r)\frac{\Delta T_r}{\Delta T_e} + a_s (1 - B_s)\frac{\Delta T_s}{\Delta T_e}}{DE_{seasonal}}\right) \qquad (4.16)$$

4.5.4 Seasonal Distribution System Efficiency

The seasonal distribution system efficiency shall be calculated using the seasonal delivery effectiveness from section 4.4.2, the equipment efficiency factor from section 4.5.1 and the thermal recovery factor from Section 4.5.3. Note that $DE_{seasonal}$, F_{equip}, F_{recov} must be calculated separately for cooling and heating conditions. Distribution system efficiency shall be determined using the following equation:

$$\eta_{dist,seasonal} = 0.98 \; DE_{seasonal} \; F_{equip} \; F_{recov} \qquad (4.17)$$

where 0.98 accounts for the energy losses from heating and cooling the duct thermal mass.

Proedures for Determining ~~Required~~ Refrigerant Charge ~~and Adequate Airflow~~ for Split System Space Cooling Systems without Thermostatic Expansion Valves

1. Overview

Failure to ~~maintain~~ obtain proper refrigerant charge ~~or proper airflow across the coil~~ reduces the seasonal energy efficiency for an air conditioner (whether a cooling only air conditioner or a heat pump). In addition, excessive refrigerant charge can cause premature compressor failure, while insufficient refrigerant charge allows compressors to overheat. ~~Very low airflow can result in icing of the coil and compressor failure.~~

To help avoid these problems and to provide a compliance credit for ~~correctly installed~~ systems installed with proper refrigerant charge, this appendix describes procedures for determining if a residential split system space cooling system has the required refrigerant charge ~~and adequate airflow across the evaporator coil~~. The applicability of these procedures have the following limitations:

- The procedures detailed in this appendix only apply to ducted split system central air conditioners and ducted split system central heat pumps that do not have thermostatic expansion valves (TXVs).
- As an alternative to the procedures detailed in this appendix, systems may substitute a TXV installed and confirmed through field verification ~~and diagnostic testing~~.
- The procedures detailed in this appendix do not apply to single packaged systems.

Note that the procedures detailed in this appendix are intended to be used after the HVAC installer has installed and charged the system in accordance with the manufacturer's specifications.

The installer shall install and charge the air conditioner and heat pump equipment in accordance with the manufacturer's instructions and specifications for the specific model equipment installed. The installer shall certify to the builder, building official and HERS rater that they have followed these instruction and specifications prior to proceeding with the procedures in this appendix.

For dwelling units with multiple systems, this procedure must be applied to each system separately.

This appendix defines two procedures, the Standard Charge ~~and Airflow~~ Measurement procedure in Section 2 and the Alternate Charge ~~and Airflow~~ Measurement procedure in Section 3. The Standard procedure shall be used when the outdoor air temperature is 55°F or above and shall always be used for HERS rater verification. HVAC installers who must complete system installation when the outdoor temperature is below 55°F shall use the Alternate procedure.

The following sections document the instrumentation needed, the required instrumentation calibration, the measurement procedure, and the calculations required for each procedure. Note: Wherever thermocouples appear in this document, thermisters can be used instead with the same requirements applying to thermisters as to thermocouples.

2. Standard Charge ~~and Airflow~~ Measurement Procedure

This section specifies the Standard charge ~~and airflow~~ measurement procedure. Under this procedure, required refrigerant charge is calculated using the *Superheat Charging Method*. The method also checks ~~and adequate~~ airflow across the evaporator coil ~~is~~ to determine whether the charge test is valid ~~calculated~~ using the *Temperature Split Method* ~~.~~ or the air flow measurement methods in Appendix X.

The Standard procedure detailed in this section shall be completed when the outdoor temperature is 55°F or higher after the HVAC installer has installed and charged the system in accordance with the manufacturer's specifications. If the outdoor temperature is between 55°F and 65°F the return dry bulb temperature shall be maintained above 65°F during the test. All HERS rater verifications are required to use this Standard procedure.

2.1 Minimum Qualifications for this Procedure

Persons carrying out this procedure need to be qualified to perform the following:

- Obtain accurate pressure/temperature readings from refrigeration manifold gauges.
- Obtain accurate temperature readings from thermometer and thermocouple set up.
- Check calibration of refrigerant gauges using a known reference pressure and thermometer/thermocouple set up using a known reference temperature.
- Determine best location for temperature measurements in ducting system and on refrigerant lineset.
- Calculate the measured superheat and temperature split.
- Determine the correct level of superheat and temperature split required, based on the conditions present at the time of the test.
- Determine if measured values are reasonable.

2.2 Instrumentation Specifications

Instrumentation for the procedures described in this section shall conform to the following specifications.

2.2.1 Digital Thermometer

Digital thermometer must have thermocouple compatibility (type K and J) and Celsius or Fahrenheit readout with:

- Accuracy: ±(0.1% of reading + 1.3º F)
- Resolution: 0.2º F

2.2.2 Thermocouples

Measurements require five (5) heavy duty beaded low-mass wire thermocouples and one (1) cotton wick for measuring wet-bulb temperatures.

2.2.3 Refrigerant Manifold Gauge Set

A standard multiport refrigerant manifold gauge with an accuracy of plus or minus 3% shall be used.

2.3 Calibration

The accuracy of instrumentation shall be maintained using the following procedures. A sticker with the calibration check date shall be affixed to each instrument calibrated.

2.3.1 Thermometer/Thermocouple Field Calibration Procedure

Thermometers/thermocouples shall be calibrated monthly to ensure that they are reading accurate temperatures. The following procedure shall be used to check thermometer/thermocouple calibration.

~~Step 1.~~Fill an insulated cup (foam) with crushed ice. The ice shall completely fill the cup. Add water to fill the cup.

~~Step 2.~~Insert two thermocouples into the center of the ice bath and attach them to the digital thermometer.

~~Step 3.~~Let the temperatures stabilize. The temperatures shall be 32°F (+/- 1°F). If the temperature is off by more than 1°F make corrections according to the manufacturer's instructions. Any thermocouples that are off by more than 3°F shall be replaced.

~~Step 4.~~Switch the thermocouples and ensure that the temperatures read on T1 and T2 are still within +/- 1°F of 32°F.

~~Step 5.~~Affix sticker with calibration check date onto thermocouple.

~~Step 6.~~Repeat the process for all thermocouples.

2.3.2 Refrigerant Gauge Field Check Procedure

Refrigerant gauges shall be checked monthly to ensure that the gauges are reading the correct pressures and corresponding temperatures. The following procedure shall be used to check gauge calibration.

~~Step 1.~~***Place a refrigerant cylinder in a stable environment and let it sit for 4 hours minimum to stabilize to the ambient conditions.***

~~Step 2.~~Attach a thermocouple to the refrigerant cylinder using duct tape so that there is good contact between the cylinder and the thermocouple.

~~Step 3.~~Insulate the thermocouple connection to the cylinder (closed cell pipe insulation can be taped over the end of the thermocouple to provide the insulation).

~~Step 4.~~Zero the low side compound gauge with all ports open to atmospheric pressure (no hoses attached).

~~Step 5.~~Re-install the hose and attach the low side gauge to the refrigerant cylinder.

~~Step 6.~~Read the temperature of the thermocouple.

~~Step 7.~~Using a pressure/temperature chart for the refrigerant, look up the pressure that corresponds to the temperature measured.

~~Step 8.~~If gauge does not read the correct pressure corresponding to the temperature, the gauge is out of calibration and needs to be replaced or returned to the manufacturer for calibration.

~~Step 9.~~Repeat the process in steps 4 through 8 for the high side gauge.

~~Step 10.~~Affix sticker with calibration check date onto refrigerant gauge.

2.4 Charge and Airflow Measurements

The following procedure shall be used to obtain measurements necessary to adjust required refrigerant charge and adequate airflow as described in the following sections.

~~Step 1.~~Establish a return air dry bulb temperature sufficiently high that the return air dry bulb temperature will be not less than 70^{o}F prior to the measurements at the end of the 15 minute period in step 2.

~~Step 2.~~Turn the cooling system on and let it run for 15 minutes to stabilize temperatures and pressures before taking any measurements. While the system is stabilizing, proceed with setting up the temperature measurements.

~~Step 3.~~Connect the refrigerant gauge manifold to the suction line service valve.

~~Step 4.~~Attach a thermocouple to the suction line near the suction line service valve. Be sure the sensor is in direct contact with the line and is well insulated from air temperature.

~~***Step 5.***~~Attach a thermocouple to measure the condenser (entering) air dry-bulb temperature. The sensor shall be placed so that it records the average condenser air entering temperature and is shaded from direct sun.

~~Step 6.~~Be sure that all cabinet panels that affect airflow are in place before making measurements. The thermocouple sensors shall remain attached to the system until the final charge is determined.

~~Step 7.~~Place wet-bulb thermocouple in water to ensure it is saturated when needed. **Do not get the dry-bulb thermocouples wet.**

~~***Step 8.***~~Insert the dry-bulb thermocouple in the supply plenum at the center of the airflow.

~~Step 9.~~At 12 minutes, insert a dry-bulb thermocouple and a wet-bulb thermocouple into the return plenum at the center of the airflow.

~~Step 10.~~At 15 minutes when the return plenum temperatures have stabilized, using the thermocouples already in place, measure and record the return (evaporator entering) air dry-bulb temperature ($T_{return,\ db}$) and the return (evaporator entering) air wet-bulb temperature ($T_{return,\ wb}$).

~~Step 11.~~Using the dry-bulb thermocouple already in place, measure and record the supply (evaporator leaving) air dry-bulb temperature ($T_{supply,\ db}$).

~~Step 12.~~Using the refrigerant gauge already attached, measure and record the evaporator saturation temperature ($T_{evaporator,\ sat}$) from the low side gauge.

~~Step 13.~~Using the dry-bulb thermocouple already in place, measure and record the suction line temperature ($T_{suction,\ db}$).

~~Step 14.~~Using the dry-bulb thermocouple already in place, measure and record the condenser (entering) air dry-bulb temperature ($T_{condenser,\ db}$).

The above measurements shall be used to adjust refrigerant charge and airflow as described in following sections.

2.5 Refrigerant Charge Calculations

The Superheat Charging Method is used only for non-TXV systems equipped with fixed metering devices. These include capillary tubes and piston-type metering devices. The following steps describe the calculations to determine if the system meets the required refrigerant charge using the measurements described in section 2.4. If a system fails, then remedial actions must be taken. If the refrigerant charge is changed and the airflow has been previously tested and shown to pass, then the airflow shall be re-tested. Be sure to complete Steps 1 and 2 of Section 2.4 before re-testing the airflow. Both the airflow and charge must be re-tested until they both sequentially pass.

~~Step 1.~~Calculate Actual Superheat as the suction line temperature minus the evaporator saturation temperature.
Actual Superheat = $T_{suction, db} - T_{evaporator, sat}$.

~~Step 2.~~Determine the Target Superheat using Table K-1 using the return air wet-bulb temperature ($T_{return, wb}$) and condenser air dry-bulb temperature ($T_{condenser, db}$).

~~Step 3.~~If a dash mark is read from Table K-1, the target superheat is less than 5°F, then the system **does not pass** the required refrigerant charge criteria, usually because outdoor conditions are too hot and dry. One of the following adjustments is needed until a target superheat value can be obtained from Table K-1 by either 1) turning on the space heating system and/or opening the windows to warm up indoor temperature; or 2) retest at another time when conditions are different. After adjustments, repeat the measurement procedure as often as necessary to establish the target superheat. Allow system to stabilize for 15 minutes before completing the measurement procedure again.

~~Step 4.~~Calculate the difference between actual superheat and target superheat (Actual Superheat - Target Superheat)

~~Step 5.~~If the difference is between minus 5 and plus 5°F, then the system **passes** the required refrigerant charge criteria.

~~Step 6.~~If the difference is greater than plus 5°F, then the system **does not pass** the required refrigerant charge criteria and the installer shall add refrigerant. After the refrigerant has been added, turn the system on and allow it to stabilize for 15 minutes before completing the measurement procedure again. Adjust refrigerant charge and repeat the measurement procedure as many times as necessary to pass the test.

~~Step 7.~~If the difference is between –5 and -100°F, then the system **does not pass** the required refrigerant charge criteria, the installer shall remove refrigerant. After the refrigerant has been removed, turn the system on and allow it to stabilize for 15 minutes before completing the measurement procedure again. Adjust refrigerant charge and repeat the measurement as many times as necessary to pass the test.

Table K-1: Target Superheat (Suction Line Temperature - Evaporator Saturation Temperature)

Condenser Air Dry-Bulb Temperature (°F)	Return Air Wet-Bulb Temperature (°F) ($T_{return, wb}$)																										
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
55	8.8	10.1	11.5	12.8	14.2	15.6	17.1	18.5	20.0	21.5	23.1	24.6	26.2	27.8	29.4	31.0	32.4	33.8	35.1	36.4	37.7	39.0	40.2	41.5	42.7	43.9	45.0
56	8.6	9.9	11.2	12.6	14.0	15.4	16.8	18.2	19.7	21.2	22.7	24.2	25.7	27.3	28.9	30.5	31.8	33.2	34.6	35.9	37.2	38.5	39.7	41.0	42.2	43.4	44.6
57	8.3	9.6	11.0	12.3	13.7	15.1	16.5	17.9	19.4	20.8	22.3	23.8	25.3	26.8	28.3	29.9	31.3	32.6	34.0	35.3	36.7	38.0	39.2	40.5	41.7	43.0	44.2
58	7.9	9.3	10.6	12.0	13.4	14.8	16.2	17.6	19.0	20.4	21.9	23.3	24.8	26.3	27.8	29.3	30.7	32.1	33.5	34.8	36.1	37.5	38.7	40.0	41.3	42.5	43.7
59	7.5	8.9	10.2	11.6	13.0	14.4	15.8	17.2	18.6	20.0	21.4	22.9	24.3	25.7	27.2	28.7	30.1	31.5	32.9	34.3	35.6	36.9	38.3	39.5	40.8	42.1	43.3
60	7.0	8.4	9.8	11.2	12.6	14.0	15.4	16.8	18.2	19.6	21.0	22.4	23.8	25.2	26.6	28.1	29.6	31.0	32.4	33.7	35.1	36.4	37.8	39.1	40.4	41.6	42.9
61	6.5	7.9	9.3	10.7	12.1	13.5	14.9	16.3	17.7	19.1	20.5	21.9	23.3	24.7	26.1	27.5	29.0	30.4	31.8	33.2	34.6	35.9	37.3	38.6	39.9	41.2	42.4
62	6.0	7.4	8.8	10.2	11.7	13.1	14.5	15.9	17.3	18.7	20.1	21.4	22.8	24.2	25.5	27.0	28.4	29.9	31.3	32.7	34.1	35.4	36.8	38.1	39.4	40.7	42.0
63	5.3	6.8	8.3	9.7	11.1	12.6	14.0	15.4	16.8	18.2	19.6	20.9	22.3	23.6	25.0	26.4	27.8	29.3	30.7	32.2	33.6	34.9	36.3	37.7	39.0	40.3	41.6
64	-	6.1	7.6	9.1	10.6	12.0	13.5	14.9	16.3	17.7	19.0	20.4	21.7	23.1	24.4	25.8	27.3	28.7	30.2	31.6	33.0	34.4	35.8	37.2	38.5	39.9	41.2
65	-	5.4	7.0	8.5	10.0	11.5	12.9	14.3	15.8	17.1	18.5	19.9	21.2	22.5	23.8	25.2	26.7	28.2	29.7	31.1	32.5	33.9	35.3	36.7	38.1	39.4	40.8
66	-		6.3	7.8	9.3	10.8	12.3	13.8	15.2	16.6	18.0	19.3	20.7	22.0	23.2	24.6	26.1	27.6	29.1	30.6	32.0	33.4	34.9	36.3	37.6	39.0	40.4
67	-	-	5.5	7.1	8.7	10.2	11.7	13.2	14.6	16.0	17.4	18.8	20.1	21.4	22.7	24.1	25.6	27.1	28.6	30.1	31.5	33.0	34.4	35.8	37.2	38.6	39.9
68	-	-	-	6.3	8.0	9.5	11.1	12.6	14.0	15.5	16.8	18.2	19.5	20.8	22.1	23.5	25.0	26.5	28.0	29.5	31.0	32.5	33.9	35.3	36.8	38.1	39.5
69	-	-	-	5.5	7.2	8.8	10.4	11.9	13.4	14.8	16.3	17.6	19.0	20.3	21.5	22.9	24.4	26.0	27.5	29.0	30.5	32.0	33.4	34.9	36.3	37.7	39.1
70	-	-	-	-	6.4	8.1	9.7	11.2	12.7	14.2	15.7	17.0	18.4	19.7	20.9	22.3	23.9	25.4	27.0	28.5	30.0	31.5	33.0	34.4	35.9	37.3	38.7
71	-	-	-	-	5.6	7.3	8.9	10.5	12.1	13.6	15.0	16.4	17.8	19.1	20.3	21.7	23.3	24.9	26.4	28.0	29.5	31.0	32.5	34.0	35.4	36.9	38.3
72	-	-	-	-	-	6.4	8.1	9.8	11.4	12.9	14.4	15.8	17.2	18.5	19.7	21.2	22.8	24.3	25.9	27.4	29.0	30.5	32.0	33.5	35.0	36.5	37.9
73	-	-	-	-	-	5.6	7.3	9.0	10.7	12.2	13.7	15.2	16.6	17.9	19.2	20.6	22.2	23.8	25.4	26.9	28.5	30.0	31.5	33.1	34.6	36.0	37.5
74	-	-	-	-	-	-	6.5	8.2	9.9	11.5	13.1	14.5	15.9	17.3	18.6	20.0	21.6	23.2	24.8	26.4	28.0	29.5	31.1	32.6	34.1	35.6	37.1
75	-	-	-	-	-	-	5.6	7.4	9.2	10.8	12.4	13.9	15.3	16.7	18.0	19.4	21.1	22.7	24.3	25.9	27.5	29.1	30.6	32.2	33.7	35.2	36.7
76	-	-	-	-	-	-	-	6.6	8.4	10.1	11.7	13.2	14.7	16.1	17.4	18.9	20.5	22.1	23.8	25.4	27.0	28.6	30.1	31.7	33.3	34.8	36.3
77	-	-	-	-	-	-	-	5.7	7.5	9.3	11.0	12.5	14.0	15.4	16.8	18.3	20.0	21.6	23.2	24.9	26.5	28.1	29.7	31.3	32.8	34.4	36.0
78	-	-	-	-	-	-	-	-	6.7	8.5	10.2	11.8	13.4	14.8	16.2	17.7	19.4	21.1	22.7	24.4	26.0	27.6	29.2	30.8	32.4	34.0	35.6
79	-	-	-	-	-	-	-	-	5.9	7.7	9.5	11.1	12.7	14.2	15.6	17.1	18.8	20.5	22.2	23.8	25.5	27.1	28.8	30.4	32.0	33.6	35.2
80	-	-	-	-	-	-	-	-	-	6.9	8.7	10.4	12.0	13.5	15.0	16.6	18.3	20.0	21.7	23.3	25.0	26.7	28.3	29.9	31.6	33.2	34.8
81	-	-	-	-	-	-	-	-	-	6.0	7.9	9.7	11.3	12.9	14.3	16.0	17.7	19.4	21.1	22.8	24.5	26.2	27.9	29.5	31.2	32.8	34.4
82	-	-	-	-	-	-	-	-	-	5.2	7.1	8.9	10.6	12.2	13.7	15.4	17.2	18.9	20.6	22.3	24.0	25.7	27.4	29.1	30.7	32.4	34.0
83	-	-	-	-	-	-	-	-	-	-	6.3	8.2	9.9	11.6	13.1	14.9	16.6	18.4	20.1	21.8	23.5	25.2	26.9	28.6	30.3	32.0	33.7
84	-	-	-	-	-	-	-	-	-	-	5.5	7.4	9.2	10.9	12.5	14.3	16.1	17.8	19.6	21.3	23.0	24.8	26.5	28.2	29.9	31.6	33.3
85	-	-	-	-	-	-	-	-	-	-	-	6.6	8.5	10.3	11.9	13.7	15.5	17.3	19.0	20.8	22.6	24.3	26.0	27.8	29.5	31.2	32.9
86	-	-	-	-	-	-	-	-	-	-	-	5.8	7.8	9.6	11.3	13.2	15.0	16.7	18.5	20.3	22.1	23.8	25.6	27.3	29.1	30.8	32.6
87	-	-	-	-	-	-	-	-	-	-	-	5.0	7.0	8.9	10.6	12.6	14.4	16.2	18.0	19.8	21.6	23.4	25.1	26.9	28.7	30.4	32.2
88	-	-	-	-	-	-	-	-	-	-	-	-	6.3	8.2	10.0	12.0	13.9	15.7	17.5	19.3	21.1	22.9	24.7	26.5	28.3	30.1	31.8
89	-	-	-	-	-	-	-	-	-	-	-	-	5.5	7.5	9.4	11.5	13.3	15.1	17.0	18.8	20.6	22.4	24.3	26.1	27.9	29.7	31.5
90	-	-	-	-	-	-	-	-	-	-	-	-	-	6.8	8.8	10.9	12.8	14.6	16.5	18.3	20.1	22.0	23.8	25.6	27.5	29.3	31.1

Table K-1: Target Superheat (Suction Line Temperature - Evaporator Saturation Temperature) (continued)

		Return Air Wet-Bulb Temperature (°F)($T_{return, wb}$)																										
		50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
Condenser Air Dry-Bulb Temperature (°F)	91	-	-	-	-	-	-	-	-	-	-	-	-	-	6.1	8.1	10.3	12.2	14.1	15.9	17.8	19.7	21.5	23.4	25.2	27.1	28.9	30.8
	92	-	-	-	-	-	-	-	-	-	-	-	-	-	5.4	7.5	9.8	11.7	13.5	15.4	17.3	19.2	21.1	22.9	24.8	26.7	28.5	30.4
	93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.8	9.2	11.1	13.0	14.9	16.8	18.7	20.6	22.5	24.4	26.3	28.2	30.1
	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	8.7	10.6	12.5	14.4	16.3	18.2	20.2	22.1	24.0	25.9	27.8	29.7
	95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.6	8.1	10.0	12.0	13.9	15.8	17.8	19.7	21.6	23.6	25.5	27.4	29.4
	96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.5	9.5	11.4	13.4	15.3	17.3	19.2	21.2	23.2	25.1	27.1	29.0
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	8.9	10.9	12.9	14.9	16.8	18.8	20.8	22.7	24.7	26.7	28.7
	98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.4	8.4	10.4	12.4	14.4	16.4	18.3	20.3	22.3	24.3	26.3	28.3
	99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.8	7.9	9.9	11.9	13.9	15.9	17.9	19.9	21.9	24.0	26.0	28.0
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.3	7.3	9.3	11.4	13.4	15.4	17.5	19.5	21.5	23.6	25.6	27.7
	101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.8	8.8	10.9	12.9	15.0	17.0	19.1	21.1	23.2	25.3	27.3
	102	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	8.3	10.4	12.4	14.5	16.6	18.6	20.7	22.8	24.9	27.0
	103	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.7	7.8	9.9	11.9	14.0	16.1	18.2	20.3	22.4	24.5	26.7
	104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.2	7.2	9.3	11.5	13.6	15.7	17.8	19.9	22.1	24.2	26.3
	105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.7	8.8	11.0	13.1	15.2	17.4	19.5	21.7	23.8	26.0
	106	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	8.3	10.5	12.6	14.8	17.0	19.1	21.3	23.5	25.7
	107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.7	7.9	10.0	12.2	14.4	16.6	18.7	21.0	23.2	25.4
	108	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.2	7.4	9.5	11.7	13.9	16.1	18.4	20.6	22.8	25.1
	109	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.9	9.1	11.3	13.5	15.7	18.0	20.2	22.5	24.7
	110	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.4	8.6	10.8	13.1	15.3	17.6	19.9	22.1	24.4
	111	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.9	8.1	10.4	12.6	14.9	17.2	19.5	21.8	24.1
	112	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.4	7.6	9.9	12.2	14.5	16.8	19.1	21.5	23.8
	113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.2	9.5	11.8	14.1	16.4	18.8	21.1	23.5
	114	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.7	9.0	11.4	13.7	16.1	18.4	20.8	23.2
	115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	8.6	10.9	13.3	15.7	18.1	20.5	22.9

2.6 ~~Adequate~~ Airflow ~~Calculations~~Verification

In order to have a valid charge test, the air flow must be verified by either passing the Temperature Split method or by one of the three measurements in Appendix X with a measured airflow in excess of 0.033 cfm/Btu rated capacity (400 cfm/12000 Btu rated capacity) (dry coil).

The temperature split method is designed to provide an efficient check to see if airflow is above the required minimum for a valid refrigerant charge test. The following steps describe the calculations using the measurement procedure described in section 2.4. If a system fails, then remedial actions must be taken. If the airflow is changed and the refrigerant charge has previously been tested and shown to pass, then the refrigerant charge shall be re-tested. Be sure to complete Steps 1 and 2 of Section 2.4 before re-testing the refrigerant charge. Both the airflow and charge must be re-tested until they both sequentially pass.

~~Step 1.~~Calculate the Actual Temperature Split as the return air dry-bulb temperature minus the supply air dry-bulb temperature. Actual Temperature Split = $T_{return, db} - T_{supply, db}$

~~Step 2.~~Determine the Target Temperature Split from Table K-2 using the return air wet-bulb temperature ($T_{return, wb}$) and return air dry-bulb temperature ($T_{return, db}$).

~~Step 3.~~ If a dash mark is read from Table K-2, then there probably was an error in the measurements because the conditions in this part of the table would be extremely unusual. If this happens, re-measure the temperatures. If re-measurement results in a dash mark, complete one of the alternate airflow measurements in Section 3.4 below.

~~Step 4.~~Calculate the difference between target and actual temperature split (Actual Temperature Split-Target Temperature Split). If the difference is within plus 3°F and minus 3°F, then the system **passes** the adequate airflow criteria.

~~Step 5.~~If the difference is greater than plus 3°F, then the system **does not pass** the adequate airflow criteria and the airflow shall be increased by the installer. Increasing airflow can be accomplished by eliminating restrictions in the duct system, increasing blower speed, cleaning filters, or opening registers. After corrective measures are taken, repeat measurement procedure as often as necessary to establish adequate airflow range. Allow system to stabilize for 15 minutes before repeating measurement procedure.

~~Step 6.~~If the difference is between minus 3°F and minus 100°F, then the measurement procedure shall be repeated making sure that temperatures are measured at the center of the airflow.

~~Step 7.~~If the re-measured difference is between plus 3°F and minus 3°F the system **passes** the adequate airflow criteria. If the re-measured difference is between minus 3°F and minus 100°F, the system passes, but it is likely that the capacity is low on this system (it is possible, but unlikely, that airflow is higher than average).

Table K-2: Target Temperature Split (Return Dry-Bulb – Supply Dry-Bulb)

Return Air Dry–Bulb (ºF) ($T_{return, db}$)	Return Air Wet-Bulb (ºF) ($T_{return, wb}$)																										
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
70	20.9	20.7	20.6	20.4	20.1	19.9	19.5	19.1	18.7	18.2	17.7	17.2	16.5	15.9	15.2	14.4	13.7	12.8	11.9	~~11.0~~	~~10.0~~	~~9.0~~	~~7.9~~	~~6.8~~	~~5.7~~	~~4.5~~	~~3.2~~
71	21.4	21.3	21.1	20.9	20.7	20.4	20.1	19.7	19.3	18.8	18.3	17.7	17.1	16.4	15.7	15.0	14.2	13.4	12.5	11.5	~~10.6~~	~~9.5~~	~~8.5~~	~~7.4~~	~~6.2~~	~~5.0~~	~~3.8~~
72	21.9	21.8	21.7	21.5	21.2	20.9	20.6	20.2	19.8	19.3	18.8	18.2	17.6	17.0	16.3	15.5	14.7	13.9	13.0	12.1	11.1	~~10.1~~	~~9.0~~	~~7.9~~	~~6.8~~	~~5.6~~	~~4.3~~
73	22.5	22.4	22.2	22.0	21.8	21.5	21.2	20.8	20.3	19.9	19.4	18.8	18.2	17.5	16.8	16.1	15.3	14.4	13.6	12.6	11.7	10.6	~~9.6~~	~~8.5~~	~~7.3~~	~~6.1~~	~~4.8~~
74	23.0	22.9	22.8	22.6	22.3	22.0	21.7	21.3	20.9	20.4	19.9	19.3	18.7	18.1	17.4	16.6	15.8	15.0	14.1	13.2	12.2	11.2	10.1	~~9.0~~	~~7.8~~	~~6.6~~	~~5.4~~
75	23.6	23.5	23.3	23.1	22.9	22.6	22.2	21.9	21.4	21.0	20.4	19.9	19.3	18.6	17.9	17.2	16.4	15.5	14.7	13.7	12.7	11.7	10.7	9.5	~~8.4~~	~~7.2~~	~~5.9~~
76	24.1	24.0	23.9	23.7	23.4	23.1	22.8	22.4	22.0	21.5	21.0	20.4	19.8	19.2	18.5	17.7	16.9	16.1	15.2	14.3	13.3	12.3	11.2	10.1	8.9	~~7.7~~	~~6.5~~
77	-	24.6	24.4	24.2	24.0	23.7	23.3	22.9	22.5	22.0	21.5	21.0	20.4	19.7	19.0	18.3	17.5	16.6	15.7	14.8	13.8	12.8	11.7	10.6	9.5	8.3	~~7.0~~
78	-	-	-	24.7	24.5	24.2	23.9	23.5	23.1	22.6	22.1	21.5	20.9	20.2	19.5	18.8	18.0	17.2	16.3	15.4	14.4	13.4	12.3	11.2	10.0	8.8	7.6
79	-	-	-	-	-	24.8	24.4	24.0	23.6	23.1	22.6	22.1	21.4	20.8	20.1	19.3	18.5	17.7	16.8	15.9	14.9	13.9	12.8	11.7	10.6	9.4	8.1
80	-	-	-	-	-	-	25.0	24.6	24.2	23.7	23.2	22.6	22.0	21.3	20.6	19.9	19.1	18.3	17.4	16.4	15.5	14.4	13.4	12.3	11.1	9.9	8.7
81	-	-	-	-	-	-	-	25.1	24.7	24.2	23.7	23.1	22.5	21.9	21.2	20.4	19.6	18.8	17.9	17.0	16.0	15.0	13.9	12.8	11.7	10.4	9.2
82	-	-	-	-	-	-	-	-	25.2	24.8	24.2	23.7	23.1	22.4	21.7	21.0	20.2	19.3	18.5	17.5	16.6	15.5	14.5	13.4	12.2	11.0	9.7
83	-	-	-	-	-	-	-	-	-	25.3	24.8	24.2	23.6	23.0	22.3	21.5	20.7	19.9	19.0	18.1	17.1	16.1	15.0	13.9	12.7	11.5	10.3
84	-	-	-	-	-	-	-	-	-	25.9	25.3	24.8	24.2	23.5	22.8	22.1	21.3	20.4	19.5	18.6	17.6	16.6	15.6	14.4	13.3	12.1	10.8

3. Alternate Charge and Airflow ~~Measurement~~ Procedure

This section specifies the Alternate charge and airflow measurement procedure. Under this procedure, the required refrigerant charge is calculated using the *Weigh-In Charging Method* and adequate airflow across the evaporator coil is calculated using the *Measured Airflow Method.*

HVAC installers who must complete system installation verification when the outdoor temperature is below 55°F shall use this Alternate procedure in conjunction with installing and charging the system in accordance with the manufacturer's specifications. HERS Raters shall not use this procedure to verify compliance.

Split system air conditioners come from the factory already charged with the standard charge indicated on the name plate. The manufacturer supplies the charge proper for the application based on their standard liquid line length. It is the responsibility of the HVAC installer to ensure that the charge is correct for each air conditioner and to adjust the charge based on liquid line length different from the manufacturer's standard.

3.1 Minimum Qualifications for this Procedure

HVAC installation technicians need to be qualified to perform the following:

- Transfer and recovery of refrigerant (including a valid Environmental Protection Agency (EPA) certification for transition and recovery of refrigerant).
- Accurately weigh the amount of refrigerant added or removed using an electronic scale.
- Calculate the refrigerant charge adjustment needed to compensate for non-standard lineset lengths/diameters based on the actual lineset length/diameter and the manufacturer's specifications for adjusting refrigerant charge for non-standard lineset lengths/diameters.

3.2 Instrumentation Specifications

Instrumentation for the procedures described in this section shall conform to the following specifications.

3.2.1 Digital Charging Scale

The digital scale used to weigh in refrigerant must have a range of .5 oz to at least 1200 oz (75 lb.). The scale's accuracy must be ± 0.25 oz.

3.3 Weigh-In Method

The following procedure shall be used by the HVAC installer to charge the system with the correct refrigerant charge.

~~Step 1.~~Obtain manufacturer's standard liquid line length and charge adjustment for alternate liquid line lengths.

~~Step 2.~~Measure and record the actual liquid line length (L_{actual}).

~~Step 3.~~Record the manufacturer's standard liquid line length ($L_{standard}$).

~~Step 4.~~Calculate the difference between actual and standard liquid line lengths ($L_{actual} - L_{standard}$).

~~Step 5.~~Record the manufacturer's adjustment for liquid line length difference per foot (A_{length}).

~~Step 6.~~Calculate the amount of refrigerant to add or remove and document the calculations on the CF-6R.

~~Step 7.~~Weigh in or remove the correct amount of refrigerant

3.4 Airflow Measurement

The airflow across the indoor evaporator coil shall be measured using one of the 3~~2~~ methods described Appendix ~~F~~ XXX - ~~Standard Procedure for Determining the Seasonal Energy Efficiencies of Residential Air Distribution Systems~~Forced Air System Fan Flow:

Section ~~4.3.7.2~~XXX.1 Diagnostic Fan Flow Using Flow Capture Hood

Section ~~4.3.7.2~~XXX.2 Diagnostic Fan Flow Using Plenum Pressure Matching

Section XXX.3 Diagnostic Fan Flow Using Flow Grid

3.5 Adequate Airflow Calculation

The measured airflow method is used to provide a check to see if airflow is above the required minimum of ~~385~~ 0.033 cfm/Btu rated capacity (400 cfm/12000 Btu rated capacity) (assumes coil is dry). The following steps describe the calculations using the measurement procedure described in Section 3.4. If a system fails, then remedial actions must be taken. The airflow must be re-tested until it passes.

~~Step 1.~~Record the measured airflow ($F_{measured}$) obtained from the measurement procedures described in Section 3.4.

~~Step 2.~~Obtain and record the rated total rated cooling capacity at ARI conditions ($C_{cooling}$) in ~~Btu.~~Tons

~~Step 3.~~Calculate the required airflow as the product of the rated cooling capacity in ~~Btu times 0.032~~Tons times 400.

~~Step 4.~~Compare the airflow measured according to section 3.4 with the required airflow.

~~Step 5.~~If the measured airflow is greater than the required airflow, then the system **passes** the adequate airflow ~~criteriuna~~criterion.

If the measured airflow is less than the required airflow, the system does not pass the adequate airflow criteria and the airflow shall be increased by the installer. Increasing airflow can be accomplished by eliminating restrictions in the duct system, increasing blower speed, cleaning filters, or opening registers. After corrective measures are taken, repeat measurement procedure.

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Residential Construction Quality for Attics: Ceiling Insulation, Air Barriers, Draft Stops, and Kneewalls

Overview

Standard practice for installing insulation in the residential construction industry is typically not free from defects. These defects lower the effective thermal resistance of the insulation resulting in increased heating and cooling demands and oversized HVAC systems. However, the energy efficiency of the envelope can be improved by paying more attention how insulation, framing and the building's air barriers are installed. Similarly, opportunities exist to improve the current protocols in the standards that are used for field verification, including the use of improved diagnostic tools. This paper focuses on calculation methods that account for the quality of construction, while assessing the energy efficiency of attics in low-rise residential buildings. Two changes are proposed to the method used to assess the thermal impact of insulation and air leakage between conditioned spaces and attics in the performance approach. The first change adds a heat loss element in the ACM models to account for the typical design and construction practice related to air barriers and draft stops. The second change modifies the effective U-factor for kneewalls and skylight shafts to account for typical installation practice. A budget-neutral approach is proposed to include a credit for those builders who use high-quality systems.

Description

Defining a standard procedure for installation, and providing a credit for it, can be a powerful tool for instructing and motivating the construction industry to improve quality and achieve rated performance from insulation. A good example is the credit for sealing ducts that was recently incorporated in the standard. Since the introduction of the credit, the industry practice in duct installation has improved substantially, even in projects where compliance credit is not claimed and testing is not carried out. The following section describes the typical industry standards and outlines the ideal installation procedure for different insulation locations. It also describes the proposed modification to the ACM rule to account for defects in standard practice.

Ceiling Insulation

For ceiling insulation to perform as rated, it should be installed in a continuous, uncompressed layer with the prescribed thickness and density. Current compliance calculation rules assume that the installation is perfectly achieved in all residences. However, field research indicates that this is a rarity rather than the norm. A new heat flow path is proposed for the ACM to account for the extra summer and winter heat flow, resulting from the typical level of defect. This heat flow path will be included in both the proposed and Standard Design budget calculation so that no change is required to meet the prescriptive requirements of the standard. A credit is proposed for builders who follow the installation procedures required to provide rated performance for ceiling insulation installation and have their installation verified by a third-party inspection.

Air Barriers and Draft Stops

For ceiling insulation to perform as rated, it should be in contact with a continuous airtight surface (the air barrier) to eliminate airflow through or around the insulation, which would result in reduced thermal performance. The current compliance rule optimistically assumes that all new residential construction has continuous flat ceilings with perfect air barriers. However, the reality is that typical architectural features in new homes, such as columns, arches, plant shelves, vaulted and dropped ceilings, provide numerous heat flow paths that bypass the ceiling insulation. In order to provide a continuous air barrier, these features should all have draft stops installed at the insulation location, but standard practice does not address this problem. Since the heat flow in these cases is carried by convection, heat flows easily from the house to the attic in winter when the house is warmer than the attic. In summer, when the house and wall cavities are cooler than the attic, the heat exchange between the house and the attic is not as significant. A modified heat flow path for heating periods is proposed to be included in the ACM rules to account for the impact of the typical levels of these defects. This heat flow path will be included in both the proposed and Standard Design budget calculation so that no change is required to meet the prescriptive requirements of the standard. A credit is proposed for builders who provide adequate air barriers and draft stops and have their installation verified by a third-party inspection.

Skylight Shafts and Attic Kneewalls

For wall insulation to perform as rated, the insulation should fill the entire stud cavity and should be enclosed by airtight surfaces on both sides. The current ACM rules implicitly assume that this is the case and does not account for poor installation practices in case of skylight shafts and attic kneewalls.[2] In reality, short kneewalls (less than one to two feet in height) are often not insulated at all. Taller kneewalls or skylight shafts are usually insulated, but the insulation is installed so that often it is not in contact with the sheetrock, and there is almost never an airtight surface on the attic side of the wall. To account for these shortcomings, new wall constructions are proposed for the ACM, so that these surfaces can be modeled more realistically. The standard U-factor for these constructions will be calculated using the same multipliers proposed for exterior walls and included in both the proposed and Standard Design budget calculation so that no change is required to meet the prescriptive requirements of the standard. A credit similar to that proposed for exterior walls is proposed for builders who follow installation procedures required to provide rated performance and have their installation verified by a third party inspection.

Benefits

Improving installation quality of ceiling insulation, air barriers, draft stops, and kneewalls improves the integrity of the building envelope. Typical construction practice results in the described defects contributing to increased energy use. Standard installation practice often ignores recommended procedures, which results in increased heating and cooling demand as described in the overview section of this report. Promoting high quality construction initiative benefits both the environment and business practices. Following the installation practices outlined in the earlier paragraphs:

1. Improves the thermal integrity in the building envelope, which would increase thermal comfort, reduce energy demand, and require a smaller cooling system (once HVAC contractors are confident that the installed insulation is providing the rated performance).
2. Increases builder and contractor customer satisfaction, reducing the potential for construction defect litigation.

Environmental Impact

The overall environmental impact of pursuing a quality assurance construction initiative is highly favorable with benefits accruing from reduced energy use.

Type of Change

The proposed approach requires a change in the performance approach which will require changes in the ACM manual and the Residential Design Manual. The following section discusses the issues involved in achieving the proposed change.

Proposed Measure Availability and Cost

In theory, there are no limitations related to the availability of this measure in the area of residential construction. The success of this initiative primarily relies on communicating acceptable installation procedures to get rated performance[3] and promoting the value of this initiative's procedures in the building community. In this case, the value of this measure can be equated to compliance credits, market differentiation due to improved construction quality, and reduced litigation potential. One critical issue related to successful implementation of this initiative involves training contractors to do the proper installation, and training HERS

[2] The vertical wall sections separating attics and conditioned space in areas where ceiling heights change.

[3] See sections describing installation procedures for Ceiling Insulation Air Barriers and Draft Stops, Skylight Shafts and Attic Kneewalls.

raters to use an appropriate field inspection procedure which would include a deep understanding of *where to look* and *what to look for*. Such training programs would ensure that the required level of competence is achieved.

This initiative will result in increased construction cost primarily due to increased labor. Currently, the construction industry is focused on streamlining the construction process to minimize labor, time and expenses. As a result not enough time or attention is given to details that are critical in obtaining a finished product consistent with the intent of the Residential Design standards. However, cost savings arising from smaller HVAC equipment size and energy savings can offset the additional labor cost and any third-party inspection cost over time.

Useful Life, Persistence and Maintenance

If the installation procedure is implemented faithfully, then the savings will be persistent and require no maintenance over the life of the building. Providing Title 24 credits for proper draft stopping and kneewall and skylight shaft insulation installation would encourage better insulation practices in the future. Continued implementation of high quality installation will eventually increase HVAC industry confidence in the thermal integrity of the building envelope, and optimizing equipment size and discouraging oversizing (which is currently done to account for flaws in construction practices).

Performance Verification

Performance verification is the key component of this initiative. Performance verification provides the assurance to the builder, and the insulation and HVAC contractors, that the thermal/pressure barrier is continuous and contiguous throughout the attic and that the ceiling envelope is performing as expected by the standards. The insulation contractor and the HERS rater must be provided with the proper training and the proper evaluation methodology to complete an accurate assessment of building envelope integrity. A detailed HERS-rater checklist or scorecard is shown in the Appendix.

Cost Effectiveness

Because this measure is being introduced as a compliance option, rather than a prescriptive measure, it is not necessary to demonstrate the cost effectiveness of the measure on a life-cycle cost basis.

Analysis Tools

MICROPAS/CALRES can be used to evaluate the energy savings impact of this initiative.

Relationship to Other Measures

Incorporation of this residential construction quality initiative in the standards will result in higher calculated heat losses, which will provide a small increase in the cost effectiveness of heating-related measures.

Methodology

In the CEC Residential Construction Quality Assessment (RCQA) project, sixty homes were evaluated in detail using diagnostic tools to assess duct and envelope leakage, HVAC airflow, and insulation installation quality. Pressure readings of interior wall cavities (such as columns, arches, duct chases, “thick” walls, etc.) were taken during house depressurization tests to assess whether these cavities were actually inside the conditioned envelope. Phase I and II Final RCQA reports consistently demonstrated that a large majority of these interior cavities are actually better connected to outdoors than indoors.

Installation requirements for thermal insulation to perform as rated is well known in the research, scientific, code writing, and insulation manufacturing communities, but the field installers remain mostly unaware of these requirements. Installers seldom realize that the installation procedures they follow result in insulation that is not performing as it has been rated to do. Building department field inspectors often just verify the presence of insulation with little attention to the details, which play a critical role in ensuring that ceiling insulation performance is not compromised. A complicating factor in performing draft-stop inspections after ceiling insulation is installed is that most of the potential problem areas are either inaccessible or the insulation hides the areas where draft stops should be in place.

The problem is rarely created solely by the insulation contractor. Truss manufacturers designing trusses that have flat framing with no cavities for thermal insulation exacerbates the problem. Framing crews that improperly install (or do not install) fire blocking and draft stops make it nearly impossible for the ceiling insulation crew to properly install the ceiling insulation. It is critical that the wall insulation crew identifies the ceiling air barrier and makes it airtight and continuous prior to drywall installation.

Architectural features encountered in today's homes vary greatly but the installation requirements for proper insulation and air barrier installation always apply and are fairly simple.

For Horizontal Insulation

By far the biggest performance problem is when insulation is not in full contact with the air barrier (usually drywall) on the bottom side. Once an air space is created under the insulation, attic air can easily convect between the air space and the attic.

Fiberglass batts are typically used in scissor-trussed vaulted ceiling areas that are too small to access with blown-in insulation after drywall is installed. Proper performance occurs when the fiberglass batts are installed in contact with the drywall. The presence of wire (electrical, phone, alarm, etc.), plumbing, truss stiffeners, etc. make this contact difficult to achieve, especially when it is installed using a stick from below – a standard trade practice (Figure 6 in Appendix 1). The same problem occurs at closets with dropped ceilings. Fiberglass batts are used to “insulate” over the top of the dropped area, creating a large air space under the batts (Figure 7 in Appendix 1). An attic mechanical equipment platform is another area where batts are normally found not to be in contact with the drywall (Figure 8 in Appendix 1).

The second problem with horizontal installations is when there is not an air barrier in place. This occurs in many different cases: a column without a draft stop, a 12-inch thick wall without a draft stop, above arches, at a soffited area where the fire blocks are not installed, etc. (Figure 9 and Figure 10 in Appendix 1). In these cases air moves through the insulation by natural convection or by pressure differences in the house caused by the furnace fan or exhaust fans. Missing draft stops may also increase air infiltration. To make these areas perform as intended, an air barrier must be installed. Air barriers installed by an insulation contractor are typically foil-faced Kraft paper or foil-faced foam board. Air barriers must be airtight and should be sealed with caulk or foam-gun applied expansive foam sealant.

For Vertical Insulation

As in the case of horizontal insulation, the primary problem degrading vertical insulation performance is the insulation not being in contact with the air barrier. Kraft-faced fiberglass batts are often used on attic kneewalls with the tabs on the Kraft facing stapled to the sides of the kneewall studs. This common installation technique creates a one-inch air space between the Kraft facing and the drywall (the air barrier). Natural convection heat transfer can be so effective in these circumstances that infrared camera imaging makes it appear as if the batt was not even installed (Figure 11 in Appendix 1). To correct this problem, the Kraft facing must be stapled to the face of the studs and held against the drywall.

Another common problem is uninsulated areas often found at drop ceilings. For example, a house with uniform 10-foot ceiling heights often has closet ceilings lowered to 8 feet (Figure 12 in Appendix 1). The 2-foot tall walls are commonly overlooked by the wall insulation crew and the crew that comes back to insulate the attic after drywall has been installed is not equipped to insulate these walls. The best fix for areas like this is to install a draft stop at the bottom truss chord, so that the draft stop and the ceiling drywall are aligned at the 10-foot height.

Yet another performance issue with vertical insulation is air intrusion from the attic side of the batt. For a vertical batt to perform at 100% or its rated R-value, it must be installed in an airtight cavity and should completely fill the cavity. Attic kneewall and skylight shaft insulation is not enclosed and has no air barrier on the attic side. Attic air can move convectively into and through the batt and reduce its performance significantly. In addition, many skylight shafts and kneewalls are non-rectangular wall cavities requiring extra care to avoid insulation gaps and voids (Figure 13 in Appendix 1).

Several improvements are available to correct these problems:

1. Install a perforated, foil paper air intrusion barrier on the attic side.
2. Increase the batt R-value.
3. Use a high-density batt that is less susceptible to air intrusion.

Phase II of the RCQA project collected field test data that helped quantify the impact of these performance issues. During house depressurization, pressure measurements were taken in accessible interior wall cavities to determine the level of connection with the attic (based on cavity pressure relative to the house). Infrared thermography was also used to assess the performance of the insulation at many of these architectural features.

From the 30-site RCQA Phase II sample, takeoffs were performed on 10 randomly selected sites to calculate the total area of interior wall cavities affected by poor draft stopping. The surface area of each wall cavity was calculated and a total cavity area was computed for each house, as shown in Appendix . Form 3Rs were prepared for each surface and are also included in Appendix . For each house, the effective UA for each defect was calculated as shown below in Example 1.

Example 1: Sample Draft Stop UA Calculation

A house (#46) has 80 ft^2 of interior wall duct chase open to the attic at the top. The winter UA of the defect is calculated assuming natural convection provides cool air from the attic into the wall at a rate that provides one-half the normal temperature difference between inside and outside. The U-factor of the uninsulated sheetrock wall is 0.299. The normal construction would be 4 ft^2 of sealed ceiling with R-38 insulation and a U-factor of 0.031. The net defect is the difference between the defect and normal construction. In summer, the air in the house will be cooler than the air in the attic and no natural convection will occur in the wall, so the summer impact is assumed to be zero for this type of defect.

Defect	80 ft^2 x 0.299 x 0.5	= 11.96 Btu/degF
Normal	4 ft^2 x 0.031 x 1	= 0.12 Btu/degF
Net Defect UA	11.96 – 0.12	= 11.8 Btu/degF

Kneewall and skylight shaft surface areas were also calculated for each of 10 houses. RCQA Project field research included both visual inspections of kneewalls/skylight shafts and infrared camera imaging. Infrared camera imaging provides surface temperature data of performing kneewall cavities relative to non-performing cavities.

Results

Table 9 – Summary of Draft Stop UA Impact (Btu/hr - °F)

	Ceiling	Summer & Winter	Winter Only
House	**Area (ft^2)**	**Defect UA**	**Defect UA**
43	2000	4.7	
46	922	1.3	11.8
37	1531	12.9	
42	3017	1.3	68.6
32	1803	1.3	
40	1474	6.9	1.1
44	880	15.5	4.1
45	955	32.0	13.2
59	1806	1.3	25.3
50	1986	1.8	115.8
Sum	16374	79	240
Average UA/ft^2 - Ceiling		0.005	0.015

Table 9 shows the results of analyzing the attic defects of 10 homes randomly selected from the RCQ study data set. The calculations for individual houses are shown in Appendix 2. The total UA of the summer and winter defects were summed and then divided by the total ceiling area to calculate the average defect UA/ft^2 of ceiling. It is proposing that these heat flows be added to all ceiling areas in houses with standard construction. A conductance for summer of 0.005 Btu/ft^2-degF will be added, and 0.02 Btu/ft^2-degF will be added to the winter heating conductance. For an R-30 ceiling, this represents an increase in heat flow of 14% in the summer and 59% in the winter.

Table 10 – Summary of Kneewall/Skylight Shaft Areas

	Floor	Kneewall/Skylight Shaft	Kneewall/Skylight
House	**Area (ft^2)**	**Area (ft^2)**	**Insulation % of R**
43	2000		-
46	922		-
37	1531	38	70%
42	3017		-
32	1803	153	35%
40	1474		-
44	880		-
45	955		-
59	1806	370	25%
50	1986		-
Average % of R			31%

Table 10 shows the results of analyzing the kneewalls in the three homes that had kneewalls. The average performance of the insulation in the kneewalls was calculated to be 31% of rated value for this sample. In order to simplify the compliance and verification, the proposal treats kneewall insulation with the same defect approach proposed for exterior walls.

Recommendations

Proposed ACM Changes

Add two new sections to the ACM manual:

3.2.X Envelope Construction Quality

Proposed Design: The ACM must allow the user to specify whether or not the proposed design will take credit for improved Envelope Construction Quality. The credit for Envelope Construction Quality must be reported in the *Special Features and Modeling Assumptions* listings on the CF-1R and C-2R.

Standard Design: The standard design shall have standard Envelope Construction Quality.

4.X Envelope Construction Quality

Standard Design: The standard design shall have standard Envelope Construction Quality.

Proposed Design: Energy credit for improved Envelope Construction Quality may be used with approved ACMs. Approved ACMs must be able to model standard and improved Envelope Construction Quality.

The reference method models wall construction quality year-round by multiplying the R-factor for wall cavity insulation by 0.69 for buildings with standard Envelope Construction Quality, and by 0.94 for cases with improved Envelope Construction Quality.

For the heating season, add 0.02 times the area to the UA of each ceiling surface with Standard Envelope Construction Quality. No modification to the UA is required if credit is claimed for improved Envelope Construction Quality.

For the cooling season, add 0.005 times the area to the UA of each ceiling assembly with Standard Envelope Construction Quality. No modification is required if credit is claimed for improved Envelope Construction Quality.

The use of improved Envelope Construction Quality shall be listed in the *Special Features and Modeling Assumptions* listings of the CF-1R and C-2R and described in detail in the ACM Compliance Supplement.

Forms

The following form will be added to the CF-6R and CF-4R to allow the insulation contractor to document compliance with these procedures and, in the case of the CF-4R, to allow the HERS rater to document verification.

Insulation Inspection Checklist for HERS Rater.

Draft CF-6R INSULATION INSTALLATION QUALITY CERTIFICATE

Site Address____ Permit ___________

☐ Insulation certificate, signed by responsible party stating, manufacturer's name, installed R-values for walls, ceiling and floors, for blown-in insulation: minimum weight per square foot

Walls

☐ No gaps
☐ No compression
☐ Insulation cut around obstructions
☐ Stapling correct: no gaps, cavity filled
☐ External channels, corners, and areas around tubs and showers insulated
☐ Small spaces filled
☐ Rim-joists insulated
☐ If blown, insulation R-value verified by measurement of depth and density (detailed protocol to be developed)

Ceiling

☐ Attic access insulated
☐ All draft stops in place
☐ All drops covered with hard covers
☐ All top plates covered
☐ Insulation covering cavities, drops, scuttles, bracing, and IC-rated fixtures

Ceiling Batts

☐ No gaps
☐ No compression
☐ Insulation cut around obstructions
☐ Batts cover trusses
☐ All venting clear: minimum one-inch clearance

Ceiling Blown-in

☐ Insulation covers entire surface
☐ Insulation uniform depth
☐ Baffles installed and eaves vents or soffit vents clear: minimum one-inch clearance
☐ Bag labels cut out and stapled to truss vertical near attic access
☐ Insulation at proper depth – insulation rulers visible and indicating proper depth
☐ Insulation R-value verified by measurement of depth and density (detailed protocol to be developed)

Floor

☐ Batts snug but not compressed or buckled
☐ All spaces insulated
☐ If web trusses, rim joists insulated

Summary

Meets all applicable requirements as specified in the Insulation Installation Procedures.

Certified____ Title___________Date ___________

Insulation Installation Procedures

Wall Insulation

Unfaced batt installation; batts shall be:

- Correctly sized to fit snugly at the sides and ends.
- Installed to completely fill the cavity.
- Cut to fit properly – there should be no gaps, nor should the insulation be doubled-over or compressed.
- Non-standard-width cavities shall be filled by batt insulation cut approximately one-inch (1”) wider than the space to be filled.
- Cut to butt-fit around wiring and plumbing, or be split (delaminated) so that one layer can fit behind the wiring or plumbing, and one layer fit in front.

Faced batt installation, where used as a vapor barrier; additional instructions:

- Facing should be placed toward living spaces.
- Faced insulation must be properly stapled over the face of the studs; it must be continuous with no penetrations.
- Stapling: the batt flange should be stapled to the face of the framing; flanges from adjacent cavities should overlap per manufacturers specifications on facing.
- Each batt should be stapled approximately every eight-inches (8”), or according to manufacturers specifications on facing.
- All tears or breaks in the facing six-inches (6”) or longer shall be sealed with duct tape or other waterproof tape. Tears and breaks in the facing should be minimal.

Narrow-framed cavities and "chinking”:

- Non-standard-width cavities shall be filled by batt insulation cut approximately one-inch (1”) wider than the space to be filled.
- Narrow spaces (two inches or less) at windows, between studs at the building's corners, and at the intersections of partitions and walls shall be filled with small pieces of insulation; care should be taken not to compress the insulation.

Special situations

Installations prior to exterior sheathing or lath:

- All exterior channels (e.g., at wall junctions and corners) must be filled with insulation.
- All exterior walls adjacent to tubs and showers must be filled with insulation.

Obstructions:

- Insulation shall be cut to fit around wiring and plumbing without compression.
- Insulation shall be placed between the sheathing and the rear of electrical boxes.
- Insulation shall be cut to fit around junction boxes.
- In cold climates, water pipes shall have at least two-thirds of the insulation between the water pipe and the outside. If the pipe is near the outside, as much insulation as possible shall be placed behind the pipe, and no insulation shall be placed between the pipe and the inside.

Rim joists:

- All rim joists shall be insulated to the same R-value as the walls.

- As necessary, insulation shall be cut to fit into the rim joist.
- An alternative to fitting insulation in a web truss located at the rim joist is to completely cover the truss with insulation, snug to the upper and lower floors.

Kneewalls and skylight shafts with framing that will support insulation:

- All kneewalls and skylight shafts shall be insulated to a minimum of R-19.
- The insulation shall be installed without gaps and with minimal compression.
- For steel-framed kneewalls and skylight shafts, external surfaces of steel studs must be covered with batts or rigid foam unless otherwise specified on the CF-1R and documented by a form 3R generated by EZFRAME.

Kneewalls and skylight shafts without framing that will support insulation:

- For steel-framed kneewalls and skylight shafts, external surfaces of steel studs must be covered with batts or rigid foam unless otherwise specified on the CF-1R and documented by a form 3R generated by EZFRAME.
- The house side of the insulation shall be in contact with the drywall or other wall finish. The attic side shall be covered with, and supported by, a facing rated for attic exposure to stop air intrusion into the insulation.

HVAC/plumbing closet:

- Insulate all walls of interior closets for HVAC and/or water heating equipment the same R-value as the exterior walls.

Batt Ceiling Insulation

Unfaced batt installation:

- Batts shall be correctly sized to fit snugly at the sides and ends.
- Batts should fill the cavity.
- Where necessary, batts shall be cut to fit properly – there should be no gaps, nor should the insulation be doubled-over or compressed. When batts are cut to fit a non-standard cavity, they should be cut to be one-inch (1”) wider than the cavity.
- Batts should be cut to butt-fit around wiring and plumbing, or be split (delaminated) so that one layer can fit behind the wiring or plumbing, and one layer fit in front.
- For batts that are taller than the trusses, full-width batts should be used so that they expand to touch each other over the trusses.
- The insulation must cover the wall top plates.
- Hard covers or draft stops should be placed over all deep drops and interior wall cavities to keep insulation in place and stop air movement. If hard covers or draft stops are missing or incomplete, they should be completed before insulation is completed.
- Required ventilation must be maintained: for eaves or soffit vents, one-inch (1”) of unblocked free air space between the roof sheathing and the insulation is required.
- Where necessary, use baffles to keep the insulation from blocking the passage of air.
- Insulation shall cover all IC rated lighting fixtures.
- Fixtures that are not IC rated (e.g., halogen lamps, heat lamps) need to be enclosed in an airtight box that meets fire codes, and the box covered with insulation. If fixtures are not IC rated and not enclosed in such a box, they should be replaced or boxed before insulation is completed.

Faced batt installation, where used as a vapor barrier: additional instructions:

- Facing should be placed toward living spaces.
- Stapling: the batt flange is stapled to the face of the framing; flanges from adjacent cavities should overlap.
- Each batt should be stapled approximately every eight-inches (8") or per manufacturer's specifications on the facing.
- All tears or breaks in the facing six-inches (6") or longer shall be sealed with appropriate tape approved by the insulation manufacturer. Tears and breaks in the facing should be minimal.

Special situations

Insulation at bridging (cross bracing):

- Batts shall be split lengthwise at the center, and packed half into the lower opening and half into the upper opening of bridging (cross bracing) of ceiling and/or floor joists.
- Alternatively, insulation is butted to the bridging and the space is filled with scrap insulation.

Rafter ceilings:

- An inch of air space should be maintained between the insulation and roof sheathing, if necessary to meet local codes
- Facings and insulation should be kept three-inches (3") away from heated flue pipes or chimneys; follow flue manufacturer's recommendations.

HVAC platform:

- Verify that appropriate batt insulation is placed below any plywood platform or walks for HVAC equipment installation and access.

Attic access:

- Permanently attach rigid foam or a batt of insulation to the access cover using adhesive or mechanical fastener.

Blown-In Ceiling Insulation

- Baffles must be placed at eaves or soffit vents to keep insulation from blocking attic ventilation. Required ventilation must be maintained: for eaves or soffit vents, one-inch (1") of unblocked free air space between the roof sheathing and the insulation is required.
- Hard covers or draft stops must be placed over all deep drops and interior wall cavities to keep insulation in place and stop air movement. If hard covers or draft stops are missing or incomplete, they should be completed before insulation is completed.
- Small, inaccessible openings shall be hand packed with pieces of batt insulation.
- Attic rulers appropriate to the material installed must be placed around attic to verify depth: one ruler for every 250 square feet, evenly distributed around the attic and clearly readable from the attic access
- Insulation shall be blown to a uniform thickness throughout the attic, with no high or low spots.
- Labels from the insulation bags should be cut out and stapled to a truss vertical near the attic opening.
- Insulation must go underneath and on both sides of obstructions such as cross-bracing and wiring.
- Insulation shall be applied all the way to the outer edge of the wall top plate.
- Insulation shall cover IC-rated lighting fixtures.
- Fixtures that are not IC rated (e.g., heat lamps) need to be enclosed in a drywall box and the box covered with insulation. If fixtures are not IC rated and not enclosed in a drywall box, they should be replaced or boxed before insulation is completed.

- There shall be no excessive compression of insulation material.
- Clearances around fossil-fuel appliances and heat-exhaust vents shall follow local fire protection codes.
- No insulation or facing shall be placed in air spaces surrounding metal chimneys or fireplaces; follow manufacturer's recommendations.
- Batt or rigid foam insulation shall be installed in areas where blown-in insulation has not been applied, such as access panels and doors.

Special situations

HVAC platform:

- Pressure-fill the areas under any plywood platform or walks for HVAC equipment installation and access or verify that appropriate batt insulation has been installed.

Attic access:

- Permanently attach rigid foam or a batt of insulation that is equal or exceeds the R-value of the insulation on the attic floor to the access cover using adhesive or mechanical fastener.

Raised Floors And Floors Over Garages

- Batts must be correctly sized to fit snugly at the sides and ends, but not be so large as to buckle – batts should be no more than one-inch (1") wider than the cavity
- Batts must be cut to fit properly – there should be no gaps, nor should the insulation be doubled-over or compressed.
- Batts should fill the cavity.
- Batts should be cut to butt-fit around wiring and plumbing, or be split (delaminated) so that one layer can fit behind the wiring or plumbing, and one layer fit in front.
- Where there is an air space between the insulation and flooring, the headers and band-joists must be insulated.
- If faced, facing should be placed toward living spaces.

Materials

- Materials shall comply with Uniform Building Code (including, but not limited to, 1997 UBC Section 707) and installed to meet all applicable fire codes.
- Materials shall meet California Quality Standards for Insulating Material, Title 24, Chapter 4, Article 3, listed in the California Department of Consumer Affairs Consumer Guide and Directory of Certified Insulating Materials.
- They shall comply with flame spread rating and smoke density requirements of Sections 2602 and 707 of the Title 24, Part 2: all exposed installations must use fire retardant facings which have been tested and certified not to exceed a flame spread of 25 and a smoke development rating of 450. Insulation facings that do not touch a ceiling, wall, or floor surface, and faced batts on the undersides of roofs with an air space between the ceiling and facing are considered exposed applications.
- Materials shall be installed according to manufacturer specifications and instructions.

R-Value And U-Value Specifications

See CF-1R for minimum requirements; for non-standard assemblies, also see applicable form 3R.

Certificates

An Insulation Certificate (IC-1) signed by the responsible party shall be provided that states that the installation is consistent with the plans and specifications for which the building permit was issued. The certificate shall also state the installing company name, insulation manufacturer's name and material identification, the installed R-value, and, in applications of blown-in insulation, the minimum installed weight-per-square-foot consistent with the manufacturer's labeled installed-design-density for the desired R-value.

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Revised Tailored Method for Allowed Lighting Power

Overview

Description

This measure revises the procedure for determining the allowed lighting power levels for interior spaces using the Tailored Method. This includes buildings or spaces in which the designer wishes to demonstrate compliance using the Tailored Method, which permits development of a power budget on a space-by-space, task-by-task basis. The Tailored Method is a mainstay of Title 24 and this proposal continues to permit its versatility to address all building types.

Benefits

This measure will reduce the allowed lighting power in buildings that use the Tailored Method. The changes will also make the Tailored Method more straightforward and clear. These benefits are achieved with no changes in the appearance or function of the regulated spaces.

Environmental Impact

There is no negative environmental impact associated with this change.In addition to saving energy, some of the newer lighting technologies last longer. This results in less lighting material being recycling and/or disposed.

Type of Change

This proposal simplifies the current Tailored Method standard. The method and approach are revised, but the energy results are intended to be the same.

Technology Measures

This method assumes the halogen infrared lamp technology as the principal illumination source for point source lighting, with the T-5 linear lighting technology for linear wallwashing and valance lighting. See discussion below.

Analysis Tools

Compliance with the revised method will require no new analysis tools. Tools such as EnergyPro would need to be modified insofar as they automatically calculate allowed lighting power.

Performance Verification

This measure adds no requirements for performance verification.

Methodology

General Approach

Initially, the Tailored Method was available to all projects as an alternative to permit the determination of lighting power using the Illuminating Engineering Society of North America (IESNA) Illuminance Selection procedure, rather than using predetermined values of LPD. However, due to gaming by designers, restrictions have been placed on the use of the Tailored Method and it has effectively become a specialized method for retail stores with separate display lighting. With this proposed standards change, the Tailored Method would return to its original intent. It is based on the following concept:

$$LPD_{Total} = LPD_{space} + LPD_{wall\ display} + LPD_{feature\ display} + LPD_{chandelier} + LPD_{very\ valuable\ displays}$$

Where:

LPD_{space}	is the allowed lighting power for the space according to the area category method. The area category method values were determined assuming a minimum of display lighting so this value is consistent with the area category methods. This is the basic allowance, which may be traded off with lighting power in other spaces of the building.
$LPD_{wall\ display}$	is the use-it-or-lose-it allowed lighting power for the walls of the space, which is based on 8 ft of useful wall height for the perimeter of the space. Different linear power densities (W/ft) are determined based on a maximum wall percentage use, with 100% for retail.
$LPD_{feature\ display}$	is the use-it-or-lose-it allowed lighting power for any type of feature display, which is based on the floor area of the space. Different power densities are determined based on a maximum percentage of use, with 10% for retail.
$LPD_{chandelier}$	is the use-it-or-lose-it allowed lighting power for chandeliers and other decorative lighting. No changes are proposed for this allowance.
$LPD_{very\ valuable\ displays}$	is the use-it-or-lose-it allowed lighting power for very valuable displays. No changes are proposed for this allowance.

Design Criteria

The IESNA "Design Guide" Handbook, Ninth Edition establishes illumination levels, revised illuminance categories, and other fundamental illumination information for the models described under "Methodology." IESNA RP-2, Retail Lighting, serves to confirm assumptions about retail design concepts that are principal in setting illumination levels and test designs.

Lighting levels were chosen as follows:

- Walls, vertical lighting levels of 50 footcandles (500 lux) average with consideration for valances (see below).
- Floor displays are determined by providing a vertical light level of 50 footcandles (500 lux) average on all four faces of displays.
- Very valuable displays are based on providing 250 footcandles (2,500 lux) over a jewelry case.

Equipment Selection

Table 11 compares the performance of halogen IR and ceramic metal halide lamps. For the purposes of analysis of retail lighting for this proposal, halogen lighting was assumed.

Table 11 – Lamp Performance of Halogen IR and Ceramic Metal Halide

Halogen and ceramic metal halide lamps have similar mean lumens and mean candlepower with similar beam spreads and are commonly used in retail display.

Lamp	Life, Hours	CBCP, Initial	Lumens, Initial	MBCP	Lumens, Mean	Input Watts	MLPW	Mean MBCP/W
100PAR/HIR/FL (GE)	3000	6300	2200	5985	2090	100	21	60
CDM35PAR30L/M/FL (Philips)	10000	7400	2000	5920	1600	45	36	132

Calculation Tool

Lighting models are developed using Lumen Micro 2000 from Lighting Technologies. The project used as an example is Nike Goddess at Fashion Island, Orange County, CA, completed in the fall of 2001 by Benya Lighting Design.

Wall Lighting

The power to achieve the "primary" light portion of wall display lighting is determined by 60 W for each 3 ft, or 20 W/ft.

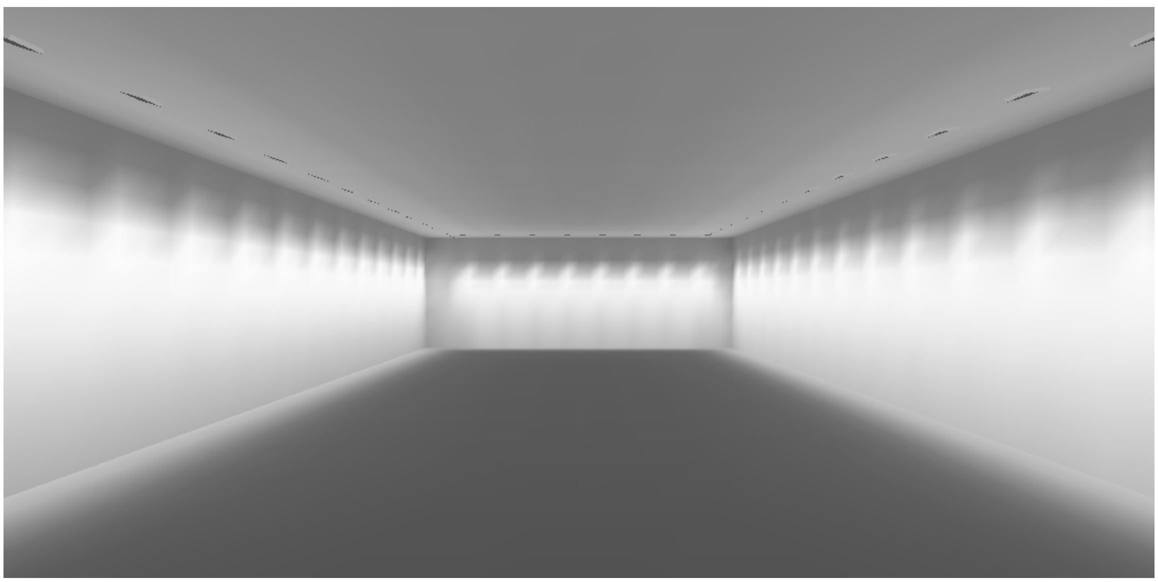

Figure 2 – Wall Display with Halogen IR Lamps

This simulation shows the use of 60-W IR lamps on 3 ft centers for accent lighting all around the perimeter of a space. This design achieves an average illumination of 50 footcandles (500 lux). There is a narrow band of lower light levels near the top of the wall that will be addressed by valance lighting below.

There remains a need for valance lighting whenever this type of key lighting is used. In a recent project in Southern California, a design using two layers of valance lighting for clothing is used in addition to key lighting as described above.

Figure 3 – Valance Lighting

The valance lighting portion requires an F28T5 lamp for each “level.” This design, with an upper and lower level, allows for two levels of clothes on display. Including ballast losses, the power for valance lighting is about 60 W per 4 ft, or 15 W per lineal foot.

Valance lighting is generally needed to illuminate the inside of a wall display as illustrated and is very common in retail lighting. A corollary to the valance is sometimes used in larger stores and supermarkets to illuminate the wall above the display when valances are not used. In either case, the amount of power is about the same.

However, as the photo shows, the valance is generally not continuous. We propose to allow 75% continuity of valances, which results in an equivalent power of 11.5 W/ft.

The total of focal (key) and valance lighting is 31.5 W per lineal foot. This combination, which is the most efficient recommended combination for the most difficult display wall lighting conditions, should permit appropriate wall display lighting under any reasonable conditions.

Next, the percentage of wall allowed for display can be applied and a value for each application determined.

Table 12 – Wall Display Allowances

Application	Area of Wall (%)	Allowed Power Density (W/ft)
Retail	70	22
Bank, Financial	10	3.1
Civic Facilities	10	3.1
Classrooms, Convention Centers	20	6.2
Dining Rooms	20	6.2
Gallery, Museum	70	22
Grocery Store	40	12.4
Hotel Spaces	10	3.1
Lobbies	20	6.2
Lounge, Recreation	20	6.2
Mall	10	3.1
Church	20	6.2
Transportation Facilities	10	3.1
Theater	20	6.2

Note: The percentages of wall areas for non-retail functions are based on recent actual designs that meet the 2001 Title 24 Nonresidential Building Standards and professional judgment.

Floor Display Lighting Allowance

The allowed amount is determined by modeling the display of floor displays in a store. A basic model consisting of a freestanding display gondola with centerpiece is shown in the foreground and a freestanding flat display is shown in the background of the simulation. The illumination consists of 60-W IR halogen flood lamps aimed at between 22° and 30° off vertical. IESNA recommendations of vertical class D and E are achieved (30 footcandle typical - 50 footcandle max), which is consistent with current practice.

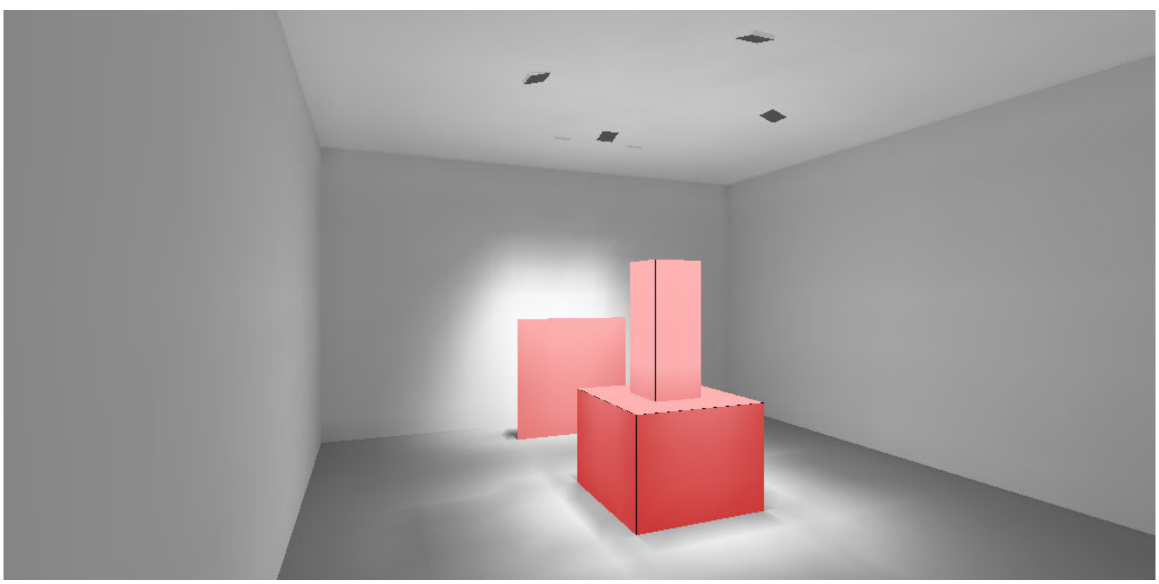

Figure 4 – Floor Display Lighting

For each gondola display, wheelchair access is assumed on two sides, and two sides are assumed to be 50% of wheelchair access to address continuous rows and other layouts. The average area of each gondola is about 6 ft x 8 ft including a narrow and wide aisle, equaling 48 ft^2, and the power is 240 W (4 x 60), resulting in a task LPD of 5.00 W/ft^2.

Assuming all floor displays, this density would result in 28% of the floor area being covered. However, historically the Tailored Method has only allowed up to 10% of the floor area. Thus, the calculated power, 5.00 W/ft², is divided by 2.8 (28%/10%) and rounded to 1.8 W/ft² for retail.

Allowances for other spaces are developed as follows. The percent of floor allowances are based on recent actual designs that meet the 2001 Title 24 Nonresidential Building Standards and professional judgment:

Table 13 – Floor Display Lighting Power Density

Application	**Area of Floor (%)**	**Allowed Power Density (W/ft^2)**
Retail	10	2.0
Bank, Financial	2.5	0.5
Civic Facilities	2.5	0.5
Classrooms, Convention Centers	2.5	0.5
Dining Rooms	1.0	0.2
Gallery, Museum	10	2.0
Grocery Store	5.0	1.0
Hotel Spaces	2.5	0.5
Lobbies	1.0	0.2
Lounge, Recreation	1.0	0.2
Mall	2.5	0.5
Church	2.5	0.5

Figure 5 – Floor Display Example

This design illustrates the use of halogen IR 60-W lamps as primary display lighting in a contemporary store recently completed and compliant with current Title 24.

Other Values

The chandelier and valuable merchandise allowances are unchanged. The chandelier allowance is available for the function areas that are identified in Table 1-P. The allowed power for ornamental lighting is limited to: a) 1 W per square foot; b) 20 W per cubic foot of ornamental lighting luminaires; or c) the actual power of ornamental luminaires.

The allowed power for the very valuable merchandise is limited to: a) the product of the area of the display case and the allowed very valuable lighting power density according to column 5 of Table 1-P; or b) the actual power of lighting for very valuable displays.

F and G Lighting Power Density Values

The assumptions and calculations underlying the LPDs for illuminance categories F and G are described in this section. The LPD values for category F and G are determined as follows:

1. Luminaire coefficients of utilization (CU) vary with room cavity ratio and are shown in Table 14. These choices are based on a T-8-based, basket style recessed fluorescent.
2. Lamp/ballast efficacy is assumed to be 75 MLPW.
3. Ceiling reflectance is assumed to be 80%, the wall reflectance 50%, and the floor reflectance 20%.
4. The light loss factor (LLF) is assumed to be 0.8.
5. The design illuminance (E) is assumed to be 100 footcandles for illuminance category F and 300 footcandles for illuminance category G.
6. Based on these assumptions, the lumen method is used to calculate the allowed LPD as follows:

$$\mathrm{LPD} = \frac{\mathrm{E}}{\mathrm{MLPW} \times \mathrm{CU} \times \mathrm{LLF}}$$

Table 14 –Assumptions and Calculations for Illuminance Categories F and G

	RCR = 2.0	RCR = 5.0	RCR = 8.0
CU	.61	.42	.31
Efficacy	75 MLPW	75 MLPW	75 MLWP
LPD for F (100 footcandles)	2.7	4.0	5.4
LPD for G (300 footcandles)	8.1	12.0	16.2

Recommendations

The following proposed language is recommended to replace the current text in §146 (b) 3. of the standards, in accordance to the modification to the Tailored Method outlined in this report.

3. Tailored method. Under the Tailored Method, the allowed lighting power density shall be calculated as specified in Subsections (b)3. A. through G.

A) To determine the allowed **general lighting power**, use either 1) or 2) below:

1) For the specific interior space, determine the Primary Function and allowed lighting power specified in Table 1-N and multiply by the area of each function in square feet, as measured from the middle of interior walls and partitions, to calculate the allowed general lighting power, or

2) For the specific interior space

(i) Determine the lighting task categories specified in the IESNA Lighting Handbook, Ninth Edition, "Design Guide" for **Horizontal Illumination**. It is permissible to have more than one task type in a space.

(ii) Determine the room cavity ratio (RCR) of each space, and the area of each task measured in square feet, in each space being designed.

(iii) Determine the lighting power density according to Table 1-S and multiply by the task area to calculate the allowed general lighting power.

Note 1: the allowed general lighting power may be used for several lighting systems and may be traded off between spaces.

Note 2: Categories E through G may be used only if the plans submitted under Section 10-103 of Title 24, Part 1 clearly identify all task spaces for such categories and the lighting designed to illuminate them. Tasks that are performed less than two hours a day may not be employed to justify use of F or G.

B) Separate wall display lighting power is permitted if specified in column 2 of Table 1-P. If so, the **allowed wall display lighting power** is the smaller of:

1) The product of the room wall lengths and the listed allowed power density (w/ft) in column 2 of Table 1-P. The length of display walls shall include the length of the interior walls and permanent full height interior partitions within the space used for actual display.

2) The actual power of wall lighting systems.

Note: Wall lighting systems shall be mounted within 48 in. of the wall and shall be of a lighting system type appropriate for wall lighting including wallwash, valance, cove, fluorescent, low voltage or line voltage modular lamps, and fiber optics.

C) Separate feature display lighting power is permitted if specified in column 3 of Table 1-P. If so, the **allowed feature display lighting power** is the smaller of:

1) The product of the area of the space and the allowed feature lighting power density listed in column 5 of table 1-P.

2) The actual power of feature display lighting systems.

Note: Display lighting systems shall be mounted no closer than 48 in. to a wall and shall be a lighting system type appropriate for feature display lighting, including track lighting; adjustable or fixed luminaires with PAR, R, MR, AR, or other projector lamp types; or employing optics providing directional display light from non-directional lamps. Lighting mounted inside of display cases shall also be considered feature display lighting.

D) Separate **ornamental lighting power** is permitted if allowed in column 4 of Table 1-P. If so, the allowed ornamental lighting power is the smaller of:

1) 1 W per square foot; or

2) 20 W per cubic foot of ornamental lighting luminaires; or

3) The actual power of ornamental luminaires.

Note: Qualifying lighting shall include chandeliers, sconces, table and floor lamps, pendant lights, and other luminaires whose primary purpose is aesthetic appearance.

E) Separate lighting power for very valuable displays is permitted if specified in column 5 of Table 1-N. If so, the **allowed lighting power for very valuable displays** is the smaller of:

1) The product of the area of the display case and the allowed very valuable lighting power density according to column 5 of Table 1-P; or

2) The actual power of *lighting* for very valuable displays.

Note: Qualifying lighting shall include internal display case lighting or external lighting employing highly directional luminaires specifically designed to illuminate the case without spill light. To qualify for this allowance, cases shall contain jewelry, fine china or crystal, precious stones, sterling silver, museum art and artifacts, and/or valuable collections.

F) Category E may be used for visually difficult tasks in private offices or workspaces for up to 50 percent of the space; the remainder of the area is allotted a 0.4 W per square foot lighting power density. When category E lighting is used, the areas must be clearly identified on the plans.

G) The **allowed lighting power** may be increased according to Table 1-R for the **allowed wall display lighting power**, the **allowed feature display lighting power**, and the **allowed lighting power for very valuable displays** by multiplying the allowed power for each by the value in Table 1-R as a function of the mounting height above the finished floor that is greater than 13 ft.

H) The **total allowed lighting power** is the sum of the **allowed general lighting power**, the **allowed wall display lighting power,** the **allowed feature display lighting power,** the **allowed ornamental lighting power,** and the **allowed lighting power for very valuable displays**. Only the general portion of the lighting power may be used for tradeoffs. The other portions of the total allowed lighting power are “use-it-or-lose-it” power allowances that may not be traded off.

Table 1-P – Tailored Method Special Lighting Power Allowances

1 Primary Function	2 Allowed Wall Display Power (W/ft)	3 Allowed Feature Display Power (W/ft²)	4 Allowed Ornamental Lighting (Y or N)	5 Allowed Very Valuable Display Power (W/ ft²) of Display Case
Auditorium	-	-	N	-
Auto repair	-	-	N	-
Bank/financial institution	3.5	0.5	Y	-
Civic facilities	3.5	0.5	Y	-
Classrooms, lecture, training, vocational room	7	-	N	-
Commercial and industrial storage	-	-	N	-
Convention, conference, multipurpose and meeting centers	7	0.5	Y	
Corridors, restrooms, stairs and support areas	-	-	N	-
Dining	7	0.5	Y	-
Electrical, mechanical rooms	-	-	N	-
Exercise center, gymnasium	-	-	N	-
Exhibit, museum	22.0	1.8	N	20
General commercial and industrial work:				
High bay	-	-	N	-
Low bay	-	-	N	-
Precision				
Grocery store	14	1.0	N	-
Housing, Public and Commons Areas				
Multi-family	-	-	Y	-
Dormitory, Senior Housing	-	-	Y	-
Hotel function area	3.5	0.5	Y	-
Kitchen, food preparation	-	-	N	-
Laundry	-	-	N	-
Library				
Reading areas	-	-	Y	-
Stacks	-	-	N	-
Lobbies:				
Hotel lobby	7	0.2	Y	-
Main entry lobby	7	0.2	N	-
Reception/waiting	7	0.2	Y	-
Locker/dressing room	-	-	N	-
Lounge/recreation	7	-	Y	-
Malls, arcades and atria	3.5	0.5	Y	-
Medical and clinical care	-	-	N	-
Office	-	-	N	-
Prisoner holding cell or jail	-	-	N	-
Police or fire stations	-	-	N	-
Post office	-	-	N	-
Religious worship (church)	7	0.5	Y	20
Retail sales, wholesale showrooms	22.0	1.8	Y	20
Transportation facilities	3.5	-	Y	-
Theaters:				
Motion picture	7	-	Y	-
Performance	7	-	Y	-
All other	-		N	-

Table 1-R Adjustments for Throw Distance (Mounting Height above Floor)

Height in feet above finished floor of luminaire(s)	Multiply by
12 or less	1.0
13	1.05
14	1.10
15	1.15
16	1.21
17	1.47
18	1.65
19	1.84
20 or more	2.04

Table 1-S Illuminance Categories A Through G Lighting Power Density Values (Watts/ft^2)

Task	Description	RCR<3.0	3.0<RCR<7.0	RCR>7.0
A	Public spaces	0.2	.0.3	0.4
B	Simple orientation for short visits	0.4	0.5	0.7
C	Working spaces where simple visual tasks are performed	0.6	0.7	1.1
D	Performance of visual tasks of high contrast and large size	1.2	1.3	1.5
E	Performance of visual tasks of high contrast and small size, or of low contrast and large size	1.8	2.3	3.0
F	Performance of visual tasks of low contrast and small size	2.7	4.0	5.4
G	Visual tasks at or near threshold	8.1	12.0	16.2

Appendix 1. Residential Construction Quality for Attics

Figure 6 – Fiberglass Batt Insulation Installed Between Scissor Trusses
The insulation will not be in contact with the air barrier due to the truss stiffener and poor installation quality.

Figure 7 – Dropped-Ceiling in Closet
Fiberglass batts are installed at the bottom truss cord to keep the loose fill ceiling insulation out of the drop. This reduces the amount of loose fill insulation required, which reduces material costs. It also prevents the insulation from being in contact with the air barrier.

Figure 8 – Attic Equipment Platform Insulated with Fiberglass Batts
The insulation will not be in contact with the air barrier (the drywall) once it is installed.

Figure 9 – Interior Wall Section
This 12-inch thick interior wall section is about to be drywalled even though it is open to the attic. The ceiling insulation installer will cover this opening with loose fill ceiling insulation. The white wire in the picture is for the thermostat.

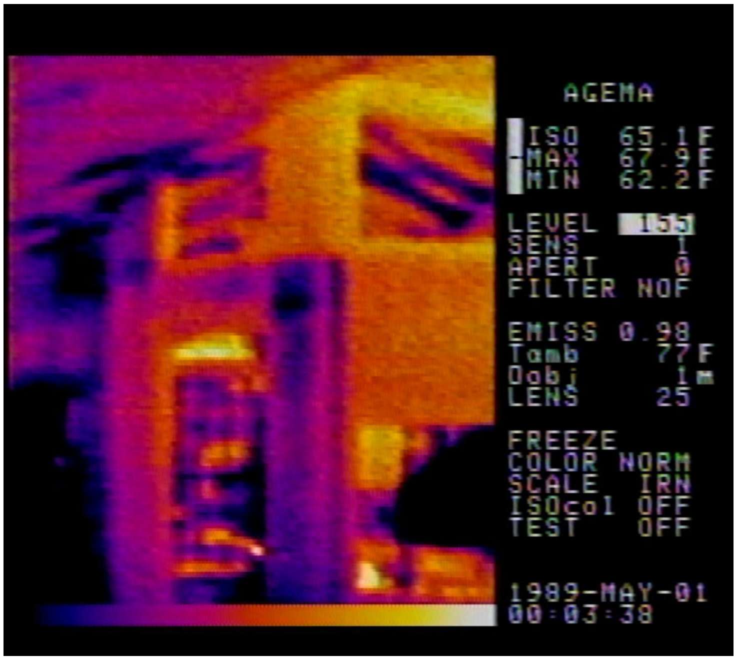

Figure 10 – Attic Connection

Infrared shows the connection to the attic through the left column but not through the right column.

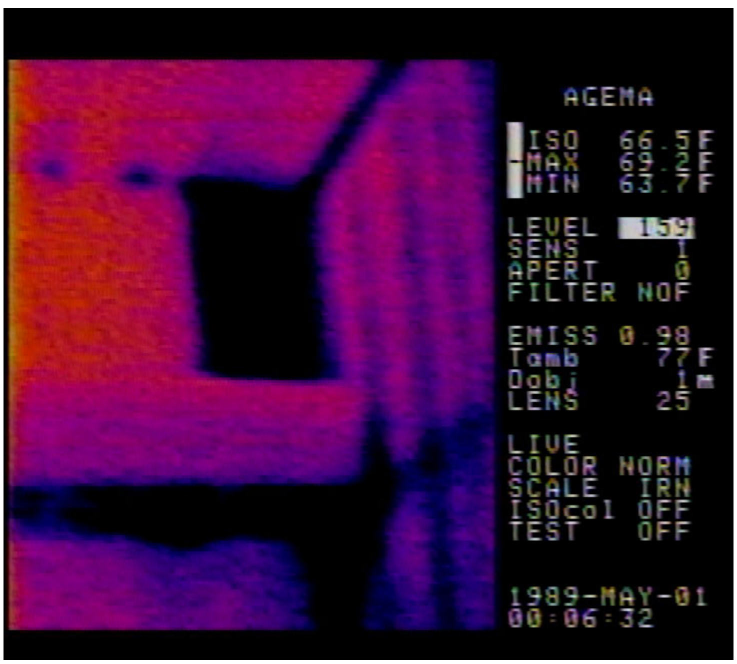

Figure 11 – Missing Attic Kneewall

Infrared shows what appears to be a missing attic kneewall batt. Inspecting the kneewall from the attic showed that this cavity was insulated and air movement behind the batt caused the performance deterioration.

Figure 12 – A Dropped Closet Ceiling Without Any Wall Insulation
Blowing the dropped section full of loose fill would have corrected the performance problem.

Figure 13 – A Skylight Shaft With R-13 Kraft-Faced Insulation
The performance problems here include; insulation not in contact with the air barrier, gaps and voids, insulation doesn't extend around the shaft corners, and attic air intrusion.

Appendix 2. Constructions and Calculation Details – Attics

```
CONSTRUCTION ASSEMBLY                                      Page 1            3R
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Project Title.......... 2005 Standards                   Date..05/28/02 08:42:18
===============================================================================
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|          User#-MP0649  User-Chitwood Energy Managemen  Run-Form 3R          |
-------------------------------------------------------------------------------

---------------------------------  Parallel Path Method
|                               |
|                               |  Reference Name . W.13.2X4.16
|                               |
|                               |  Description .... Wall R-13 2x4 16oc
|                               |
|                               |  Type ........... Wall
|                               |
|                               |  R-Value ........ 13 Hr-sf-F/Btu
|                               |
|                               |  Framing
|                               |    Material ..... FIR.2X4
|                               |    Type ......... Wood
|                               |    Description .. 2x4 fir
|                               |    Spacing ...... 16 inches on center
|                               |    Framing Frac.. 0.15
|                               |
---------------------------------
 Sketch of Construction Assembly


LIST OF CONSTRUCTION COMPONENTS
       Material                                                Cavity     Frame
         Name              Description                         R-Value   R-Value
     ------------- ---------------------------------------- --------- ---------
 O.  FILM.EX       Exterior air film: winter value              0.17      0.17
 1.  STUCCO.0.88   0.875 in stucco                              0.17      0.17
 2.  BLDG.PAPER    Building paper (felt)                        0.06      0.06
 3c. BATT.R13      R-13 batt insul (cavity = 3.5 in)           13.00       --
 3f. FIR.2X4       2x4 fir                                       --       3.46
 4.  GYP.0.50      0.50 in gypsum or plaster board              0.45      0.45
 I.  FILM.IN.WLL   Inside air film: heat sideways               0.68      0.68
```

```
                                                    --------- ---------
                              Total Unadjusted R-Values   14.53      5.00

FRAMING ADJUSTMENT CALCULATION

              Cavity               Framing              Total
          -------------------   -------------------   ----------------

U-Factor: (1 /  14.53 x 0.85) + (1 /   5.00 x 0.15) =  0.088 Btu/hr-sf-F
                                                       =====

Total R-Value:                           1 /  0.088  =  11.30 hr-sf-F/Btu
```

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CONSTRUCTION ASSEMBLY                                      Page 2            3R
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|          User#-MP0649  User-Chitwood Energy Managemen  Run-Form 3R          |
-------------------------------------------------------------------------------

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|                               |
|                               |  Reference Name . R.38.2X4.24
|                               |
|                               |  Description .... Roof R-38 2x4 24oc
|                               |
|                               |  Type ........... Roof
|                               |
|                               |  R-Value ........ 38 Hr-sf-F/Btu
|                               |
|                               |  Framing
|                               |    Material ..... FIR.2X4
|                               |    Type ......... Wood
|                               |    Description .. 2x4 fir
|                               |    Spacing ...... 24 inches on center
|                               |    Framing Frac.. 0.07
|                               |
---------------------------------
 Sketch of Construction Assembly
```

LIST OF CONSTRUCTION COMPONENTS

	Material Name	Description	Cavity R-Value	Frame R-Value
O.	FILM.EX	Exterior air film: winter value	0.17	0.17
1.	SHNGL.ASPHLT	Asphalt shingle roofing	0.44	0.44
2.	BLDG.PAPER	Building paper (felt)	0.06	0.06
3.	PLY.0.50	0.50 in plywood	0.62	0.62
4.	AIR.RF.3.50	3.5 in & greater air space: heat flow up	0.80	0.80
5.	BATT.R27.U	R-27 batt insulation	27.00	27.00
6c.	BATT.R11.U	R-11 batt insul (cavity > 3.5 in)	11.00	--
6f.	FIR.2X4	2x4 fir	--	3.46
7.	GYP.0.50	0.50 in gypsum or plaster board	0.45	0.45
I.	FILM.IN.RF	Inside air film: heat flow straight up	0.61	0.61
		Total Unadjusted R-Values	41.15	33.62

```
FRAMING ADJUSTMENT CALCULATION

               Cavity               Framing               Total
          -------------------   -------------------   ----------------

U-Factor: (1 /  41.15 x 0.93) + (1 /  33.62 x 0.07) =  0.025 Btu/hr-sf-F
                                                       =====

Total R-Value:                           1 /  0.025  =  40.51 hr-sf-F/Btu
```

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CONSTRUCTION ASSEMBLY                                     Page 3            3R
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|         User#-MP0649  User-Chitwood Energy Managemen  Run-Form 3R             |
--------------------------------------------------------------------------------

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|                               |
|                               |  Reference Name . R.30.2X12.16
|                               |
|                               |  Description .... Roof R-30 2x12 16oc
|                               |
|                               |  Type ........... Roof
|                               |
|                               |  R-Value ........ 30 Hr-sf-F/Btu
|                               |
|                               |  Framing
|                               |    Material ..... FIR.2X12
|                               |    Type ......... Wood
|                               |    Description .. 2x12 fir
|                               |    Spacing ...... 16 inches on center
|                               |    Framing Frac.. 0.10
|                               |
---------------------------------
 Sketch of Construction Assembly


LIST OF CONSTRUCTION COMPONENTS
       Material                                                Cavity     Frame
         Name             Description                          R-Value   R-Value
     ------------- ---------------------------------------- --------- ---------
 O.  FILM.EX       Exterior air film: winter value             0.17      0.17
 1.  SHNGL.ASPHLT  Asphalt shingle roofing                     0.44      0.44
 2.  BLDG.PAPER    Building paper (felt)                       0.06      0.06
 3.  PLY.0.50      0.50 in plywood                             0.62      0.62
 4c. AIR.RF.1.75   1.75 in (approx) air space: heat flow up    0.77       --
 4f. FIR.2X12      2x12 fir                                     --       11.14
 5c. BATT.R30.U    R-30 batt insul (cavity > 9.25 in)         30.00       --
 6.  GYP.0.50      0.50 in gypsum or plaster board             0.45      0.45
 I.  FILM.IN.RF    Inside air film: heat flow straight up      0.61      0.61
                                                            --------- ---------
                                  Total Unadjusted R-Values   33.12     13.49
```

```
FRAMING ADJUSTMENT CALCULATION

              Cavity               Framing              Total
          -------------------   -------------------   ----------------


U-Factor: (1 /  33.12 x 0.90) + (1 /  13.49 x 0.10) =  0.035 Btu/hr-sf-F
                                                       =====

Total R-Value:                            1 /  0.035   =  28.91 hr-sf-F/Btu
```

```
CONSTRUCTION ASSEMBLY                                      Page 4          3R
==============================================================================
Project Title.......... 2005 Standards                   Date..05/28/02 08:42:18
==============================================================================
|     MICROPAS6 v6.01  File-2005_STD  Wth-CTZ12S92  Program-FORM 3R          |
|          User#-MP0649  User-Chitwood Energy Managemen  Run-Form 3R         |
------------------------------------------------------------------------------

---------------------------------  Parallel Path Method
|                               |
|                               |  Reference Name . HATCH
|                               |
|                               |  Description .... Roof R-0 2x4 24oc
|                               |
|                               |  Type ........... Roof
|                               |
|                               |  R-Value ........ 0 Hr-sf-F/Btu
|                               |
|                               |  Framing
|                               |    Material ..... FIR.2X4
|                               |    Type ......... Wood
|                               |    Description .. 2x4 fir
|                               |    Spacing ...... 24 inches on center
|                               |    Framing Frac.. 0.07
|                               |
---------------------------------
 Sketch of Construction Assembly
```

LIST OF CONSTRUCTION COMPONENTS

	Material Name	Description	Cavity R-Value	Frame R-Value
O.	FILM.EX	Exterior air film: winter value	0.17	0.17
1.	SHNGL.ASPHLT	Asphalt shingle roofing	0.44	0.44
2.	BLDG.PAPER	Building paper (felt)	0.06	0.06
3.	PLY.0.50	0.50 in plywood	0.62	0.62
4.	AIR.RF.3.50	3.5 in & greater air space: heat flow up	0.80	0.80
5c.	R0.PLACEHOLD	R-0 Place Holder	0.00	--
5f.	FIR.2X4	2x4 fir	--	3.46
6.	GYP.0.50	0.50 in gypsum or plaster board	0.45	0.45
I.	FILM.IN.RF	Inside air film: heat flow straight up	0.61	0.61
		Total Unadjusted R-Values	3.15	6.61

```
FRAMING ADJUSTMENT CALCULATION

               Cavity               Framing              Total
          -------------------   -------------------   ----------------

U-Factor: (1 /   3.15 x 0.93) + (1 /   6.61 x 0.07) =  0.306 Btu/hr-sf-F
                                                       =====

Total R-Value:                          1 /  0.306   =   3.27 hr-sf-F/Btu
```

```
CONSTRUCTION ASSEMBLY                                      Page 5            3R
===============================================================================
Project Title.......... 2005 Standards                   Date..05/28/02 08:42:18
===============================================================================
|     MICROPAS6 v6.01  File-2005_STD  Wth-CTZ12S92  Program-FORM 3R           |
|          User#-MP0649  User-Chitwood Energy Managemen  Run-Form 3R          |
-------------------------------------------------------------------------------

---------------------------------  Parallel Path Method
|                               |
|                               |  Reference Name . KNEEWALL
|                               |
|                               |  Description .... Roof R-0 2x4 24oc
|                               |
|                               |  Type ........... Roof
|                               |
|                               |  R-Value ........ 0 Hr-sf-F/Btu
|                               |
|                               |  Framing
|                               |    Material ..... FIR.2X4
|                               |    Type ......... Wood
|                               |    Description .. 2x4 fir
|                               |    Spacing ...... 24 inches on center
|                               |    Framing Frac.. 0.07
|                               |
---------------------------------
 Sketch of Construction Assembly


LIST OF CONSTRUCTION COMPONENTS
       Material                                                Cavity     Frame
         Name             Description                          R-Value   R-Value
     ------------- ---------------------------------------- --------- ---------
 O.  FILM.EX       Exterior air film: winter value               0.17      0.17
 1.  SHNGL.ASPHLT  Asphalt shingle roofing                       0.44      0.44
 2.  BLDG.PAPER    Building paper (felt)                         0.06      0.06
 3.  PLY.0.50      0.50 in plywood                               0.62      0.62
 4.  AIR.RF.3.50   3.5 in & greater air space: heat flow up      0.80      0.80
 5c. R0.PLACEHOLD  R-0 Place Holder                              0.00       --
 5f. FIR.2X4       2x4 fir                                        --       3.46
 6.  GYP.0.50      0.50 in gypsum or plaster board               0.45      0.45
 I.  FILM.IN.WLL   Inside air film: heat sideways                0.68      0.68
                                                            --------- ---------
                              Total Unadjusted R-Values          3.22      6.68
```

```
FRAMING ADJUSTMENT CALCULATION

              Cavity                Framing               Total
          -------------------   -------------------   ----------------


U-Factor: (1 /   3.22 x 0.93) + (1 /   6.68 x 0.07) =  0.299 Btu/hr-sf-F
                                                       =====

Total R-Value:                            1 /  0.299  =   3.34 hr-sf-F/Btu
```

Defect Calculation Details

Site Number	43					
CFA	2000		Ceiling	2000	ft^2	

List of Defects keyed to calculations

1. Eave vent missing insulation 12 square feet, no insulation
2. Attic access hatch 4.6 square feet

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	12.0	0.025	0.306	0.281	1	3.4
Element 2	4.6	0.025	0.306	0.281	1	1.3
Element 3					1	
Element 4					1	
Sum						4.7
					U/ft^2 Ceil	0.002

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5						
Element 6						
Element 7						
Element 8						
Sum						
					U/ft^2 Ceil	

Site Number	46					
CFA	1650		Ceiling	922	ft^2	

List of Defects keyed to calculations

1. Attic access hatch 4.6 square feet
5. Duct chase open to attic, 80 square feet, no insulation

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	4.6	0.025	0.306	0.281	1	1.3
Element 2					1	
Element 3					1	
Element 4					1	
Sum						1.3
					U/ft^2 Ceil	0.001

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	4.0	0.031	80	0.299	0.5	11.8
Element 6						
Element 7						
Element 8						
Sum						11.8
					U/ft^2 Ceil	0.013

Site Number	37					
CFA	2499		Ceiling	1531	ft^2	

List of Defects keyed to calculations

1. Living vaulted ceiling area 468 square feet performing at 60% of R-30

2 & 3 Two attic access hatches one vertical & one horizontal 4.6 square feet each, no insulation.

4. Missing batts in bedroom vault 8 square feet, no insulation

9. Attic kneewall to garage attic 38 square feet, performing at 70%

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	468.0	0.035	0.053	0.018	1	8.4
Element 2	4.6	0.025	0.306	0.281	1	1.3
Element 3	4.6	0.088	0.299	0.211	1	1.0
Element 4	8.0	0.025	0.306	0.281	1	2.2
Sum						12.9
					U/ft^2 Ceil	0.008

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5						
Element 6						
Element 7						
Element 8						
Sum						
					U/ft^2 Ceil	

Site Number	42					
CFA	3017		Ceiling	3017	ft^2	

List of Defects keyed to calculations

1. Attic hatch 4.6 square feet, R-0

5. 256 sq.ft. sofit at R-0

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	4.6	0.025	0.306	0.281	1	1.3
Element 2					1	
Element 3						
Element 4						
Sum						1.3
					U/ft^2 Ceil	0.000

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	256.0	0.031	256	0.299	1	68.6
Element 6						
Element 7						
Element 8						
Sum						68.6
					U/ft^2 Ceil	0.023

Site Number	32					
CFA	1803		Ceiling	1803	ft^2	

List of Defects keyed to calculations

1. 4.6 sq.ft. attic hatch
2. 145 sq.ft. attic kneewall at 50% performance, R-13
3. 8 sq.ft. of attic kneewall at R-0

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	4.6	0.025	0.306	0.281	1	1.3
Element 2						
Element 3						
Element 4						
Sum						1.3
					U/ft^2 Ceil	0.001

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5						
Element 6						
Element 7						
Element 8						
Sum						
					U/ft^2 Ceil	

Site Number	40					
CFA	1474		Ceiling	1474	ft^2	

List of Defects keyed to calculations

1. 4.6 sq.ft. attic hatch at R-1
2. 20 sq.ft. no insulation at recessed light fixtures
5. 4 sq.ft. linen cabinet drop
9. 24 sq.ft. fireplace kneewall

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	4.6	0.025	0.306	0.281	1	1.3
Element 2	20.0	0.025	0.306	0.281	1	5.6
Element 3						
Element 4						
Sum						6.9
					U/ft^2 Ceil	0.005

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	4.0	0.025	4	0.299	1	1.1
Element 6						
Element 7						
Element 8						
Sum						1.1
					U/ft^2 Ceil	0.001

Site Number	44					
CFA	1430		Ceiling	880	ft^2	

List of Defects keyed to calculations

1. 20 sq.ft. insulation blown away from attic eyebrow vents
2. 6.25 attic access hatch at R-0
3. 30 sq.ft. no insulation at eaves
5. 95 sq.ft. open duct chase

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	20.0	0.031	0.306	0.275	1	5.5
Element 2	6.3	0.031	0.306	0.275	1	1.7
Element 3	30.0	0.031	0.306	0.275	1	8.3
Element 4						
Sum						15.5
					U/ft^2 Ceil	0.018

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	2.0	0.031	95	0.088	0.5	4.1
Element 6						
Element 7						
Element 8						
Sum						4.1
					U/ft^2 Ceil	0.005

Site Number	45					
CFA	1750		Ceiling	955	ft^2	

List of Defects keyed to calculations

1. 6.25 sq.ft. attic hatch at R-0
2. 20 sq.ft insulation moved under eyebrow vent
3. 90 sq.ft. no insulation at eaves
5. 68 sq.ft. open duct chase
6. 21 sq.ft. data panel cavity open to attic

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	6.3	0.031	0.306	0.275	1	1.7
Element 2	20.0	0.031	0.306	0.275	1	5.5
Element 3	90.0	0.031	0.306	0.275	1	24.8
Element 4						
Sum						32.0
					U/ft^2 Ceil	0.033

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	2.0	0.031	68	0.299	0.5	10.1
Element 6	0.4	0.031	21	0.299	0.5	3.1
Element 7						
Element 8						
Sum						13.2
					U/ft^2 Ceil	0.014

Site Number	59					
CFA	1806		Ceiling	1806	ft^2	

List of Defects keyed to calculations

1. 4.6 sq.ft. attic access hatch at R-0
5. 128 sq.ft. linen cabinet open to attic
6. 42 sq.ft. plant shelf open to attic
9. 350 sq.ft. kneewall at 50% insulation performance
10. 20 sq.ft. kneewall at R-1

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	4.6	0.031	0.306	0.275	1	1.3
Element 2					1	
Element 3					1	
Element 4						
Sum						1.3
					U/ft^2 Ceil	0.001

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	4.0	0.031	128	0.299	0.5	19.0
Element 6	0.4	0.031	42	0.299	0.5	6.3
Element 7						
Element 8						
Sum						25.3
					U/ft^2 Ceil	0.014

Site Number	50					
CFA	1986		Ceiling	1986	ft^2	

List of Defects keyed to calculations

1. 6.25 sq.ft. attic access

5. 789 sq.ft. of interior wall surface open to attic, should be 85 sq.ft.

Ceiling Calculations

Winter & Summer	Area	U Perfect	U Actual	DeltaU	DeltaT F	UA
Element 1	6.3	0.025	0.306	0.281	1	1.8
Element 2						
Element 3						
Element 4						
Sum						1.8
					U/ft^2 Ceil	0.001

	Perfect Assumption		Actual Condition			
Winter Only	Area	Perfect U	Area	U Actual	DeltaT F	UA
Element 5	85.0	0.025	789	0.299	0.5	115.8
Element 6						
Element 7						
Element 8						
Sum						115.8
					U/ft^2 Ceil	0.058